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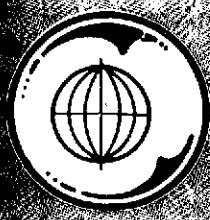
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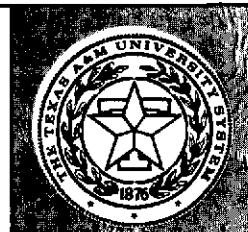
# REMOTE SENSING CENTER ANNUAL TECHNICAL ACTIVITY SUMMARY

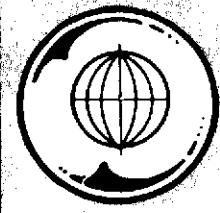
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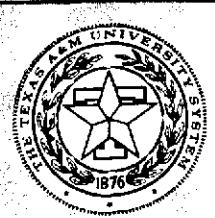


TEXAS A&M UNIVERSITY  
REMOTE SENSING CENTER  
COLLEGE STATION, TEXAS





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REMOTE SENSING CENTER**  
COLLEGE STATION, TEXAS



# REMOTE SENSING CENTER

## TECHNICAL ACTIVITY SUMMARY

September 1972 - September 1973

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REMOTE SENSING CENTER  
TECHNICAL ACTIVITY SUMMARY  
September 1972 - September 1973

#### I. INTRODUCTION

The Remote Sensing Center of Texas A&M University conducts multidisciplinary and interdisciplinary research and applications programs utilizing remote sensing techniques for earth resources surveys and environmental monitoring. This summary report describes the 1972-1973 program and is the sixth report in this series. The majority of the projects described are part of long-term programs of the Center and this report represents interim activities, however several of the projects reached scheduled milestones providing significant results.

Since its initiation in November 1968, the Remote Sensing Center has adhered to specific guidelines which include (i) defining research and application problems having relevance to the present needs in earth resources surveys and environmental monitoring, (ii) examining these areas to establish individually the engineering, data processing, and geoscience problems for which remote sensing techniques could contribute positively to solutions or improved definitions,

(iii) conducting research and applications projects on specific aspects of these individual problems, and (iv) distributing the results of these studies to the field personnel responsible for resource or environmental management. The fundamental motivation for this effort is to achieve realistic application for the new tools available in the field of remote sensing.

During the last three years the program has accelerated rapidly with a substantial increase in the number of applications projects, especially in agricultural applications. Of particular note in the 1972-73 program is the establishment of cooperative projects with federal and state user agencies. These activities tend to better focus the Center's efforts and to improve the efficiency of the transfer of research results into user applications. Cooperative projects are being conducted with the Soil Conservation Service (USDA), Agricultural Research Service (USDA), Corps of Engineers, Texas Department of Agriculture, Office of the Governor (Texas), among others. In addition to these projects, the 1972-73 program yielded significant contributions to research and applications efforts in the remote sensing field. Of particular note in this Summary is the work by M.D. Schwebel and P.E. White on the determination of water quality parameters using visible-region sensors;

by K.R. Moore on the feasibility of remote determination of wildlife habitat in Texas; by R.H. Haas and D.W. Deering on the correlation of spectral band ratios to vegetation development; by J.A. Schell on techniques for processing ERTS-1 MSS data; by F.J. Bruns on development of a low-cost color digital image display system; by R.W. Toler and W.C. Odle on remote measurements of vegetation stress; by J.A. Permenter and W.C. Nordhaus on development of a real-time signal processor and classifier for radar sensing of Arctic ice; by G.J. Wilhelm on formulation of a model for volume scattering of electromagnetic energy from rough surfaces; by C.L. Kroll and T.G. Sibley on passive microwave sensing of soil moisture in the presence of vegetation; and by W.T. Mayo and T.C. Sheives on preliminary development of a laser sensor for oil spill detection.

This report contains a summary of each research area with reference to technical reports detailing the recent results. The documentations contained in this report does not encompass the whole of the Remote Sensing Center program, but it emphasizes the major projects. In previous annual reports the appendix included copies of many of the technical reports relating to the project activity, however the volume of the 1972-73 material exceeds the level where this is still practical. Consequently, the appendices consist

primarily of the abstracts or summaries of these reports, and a complete listing of the current publications is included in Section VII.

## II. ORGANIZATION

The Remote Sensing Center is a consortium of four colleges of Texas A&M University: Agriculture, Engineering, Geosciences and Science. Because of this unique organization, the Center has been successful in establishing workable intercollege projects. Administratively the Center was formed as a division of the Texas Engineering Experiment Station. However, because of the growth of its agricultural applications effort, the Center has also been designated a division of the Texas Agricultural Experiment Station. This added dimension to the administrative structure enables the Center to interface more effectively with agriculturists throughout Texas.

The Center is structured into seven laboratories. Four of these are devoted primarily to applications projects and three provide the supporting technology. The laboratories are: Vegetation Systems Laboratory, headed by Dr. R.H. Haas; Plant Protection Laboratory, headed by Dr. R.W. Toler; Data Analysis Laboratory, headed by J.A. Schell; Electro-optical Systems Laboratory, headed by Dr. W.T. Mayo; Environmental Monitoring Laboratory, headed by Dr. W.P. James; Space Oceanography Laboratory headed by Dr. G.L. Huebner; and Microwave and Infrared Systems Laboratory, headed by Dr. J.W. Rouse, Director of the Center.

### III. PROGRAM DEVELOPMENT

The orientation and emphasis of the Remote Sensing Center program are strongly influenced by the National Aeronautics and Space Administration as expressed in the goals of NASA Grant NGL 44-001-001, which provides the basic support for major segments of this work. Many of the contract supported studies are a direct result of activities initiated under this grant program, consequently the grant activities form an integral part of the overall program. Prior to 1973, the grant activities tended toward fundamental research in sensor technology and data analysis. This emphasis is evident in previous Annual Summaries. This year the emphasis was redirected to concentrate on applications of remote sensing techniques, and the work in the Center this year reflects this new direction. This reorientation was well suited to the multidisciplinary structure of the Remote Sensing Center, which was established specifically for the purpose of adapting these new techniques to resource monitoring problems in Texas. In addition, it promoted utilization of a wider range of the University's earth scientists. As a direct result of the 1973 reorientation, the Center increased the personnel in the applications groups, particularly the Vegetation Systems

Laboratory. The number of full-time professionals was increased, and the previous predominance of master degree level graduate students was changed to a predominance of doctoral level graduate students.

During this year, several application-oriented projects, called Action Projects, have been established in cooperation with state and/or federal agencies in which a variety of remote sensing techniques are being applied.

Among these Action Projects are:

Land Resource Management - A cooperative project among USDA Soil Conservation Service (SCS), Texas Agricultural Experiment Station, and Remote Sensing Ceter was initiated to evaluate remote sensing to assist in land resource management. The feasibility and cost effectiveness of applying remote sensing techniques to aid in land resource inventory tasks performed by the SCS: (1) updating soil surveys, (2) conducting "Conservation Needs Inventory" and (3) other types of inventories associated with land resource management are being determined. NASA/JSC obtained aerial photography of Brazos County during May 1973 in support of this project. Additional flights are scheduled for late 1973 and mid-1974. SCS personnel from the Temple, Texas office have been assigned to the project to participate in a training program and the collection of ground data. Phase I of this cooperative

project has been completed and Phase II (field data collection) is currently in progress.

Cotton Insects - This is a cooperative project between USDA Agricultural Research Service (ARS) and Remote Sensing Center personnel to obtain synoptic information needed in the state-wide effort to control the advance of the bollworm and boll weevil in Texas. Control of cotton insects is a matter of enormous economic significance in Texas. The ARS is conducting a pilot project of Frio County, Texas to determine insect population dynamics and effective eradication methods. It has been determined that timely agricultural land use data are extremely important for effective use of the inventory and control techniques. Airborne and ERTS-1 data have been acquired for Frio County. The ERTS-1 data are being computer processed to isolate and identify crop types, location, and acreages.

Coastal Dredging - This is a cooperative project among U.S. Corps of Engineers, Civil Engineering Department, and Remote Sensing Center personnel to quantify the impact of dredging activities in Galveston Bay. The project was initiated as a ground-based study for the Corps of Engineers. The Center has offered to acquire and analyze

remote sensing data as a compliment to the ongoing effort so as to determine the utility and cost effectiveness of remote sensing techniques in this application. ERTS-1 data have been acquired and several overflights by the Texas A&M University photo-equipped aircraft have been conducted.

Crop Diseases - A cooperative effort among the Texas Department of Agriculture (Quarantine Division), Texas Agricultural Experiment Station, and Remote Sensing Center personnel has been established to apply aerial inventorying methods in the assessment of select crop diseases. The initial effort is concentrating on a virus of St. Augustinegrass, which is presently under strict quarantine in Texas. This commercial crop is normally surveyed manually by Texas Department of Agriculture personnel at considerable cost. Preliminary tests confirm that an appreciable saving in time and money can be realized using a multi-band aerial photographic method in lieu of manual inspections. Extension of the techniques to monitoring wheat and sorghum are under investigation.

Urban Planning and Land Use - This project is an expansion of the Woodlands Project being conducted by the Center for Mitchell Associates in Houston, Texas. The

expanded project is being formulated as a cooperative effort with the Texas Real Estate Institute, Department of Agricultural Economics, and the College of Agriculture. Initial plans have been formulated along the lines of the Cornell University land use inventory for New York. This overall project area is associated with activities of the newly formed Interagency Council on National Resources and Environment recently established in Texas by Governor Briscoe. This council has a Remote Sensing Task Force as a subgroup which includes Remote Sensing Center personnel in its membership. This state-wide effort is similar to the Arizona activity and is being encouraged by NASA.

#### IV. APPLICATIONS

##### A. Vegetation Systems

The Vegetation Systems Laboratory in the Remote Sensing Center was established in 1972, to coordinate remote sensing investigations related to the use of renewable natural resources. This laboratory under the direction of Dr. R.H. Haas, Associate Professor in Range Science, has expanded its program during this year to include a wide variety of application oriented studies. This applications oriented program is a joint effort of Texas Agricultural Experiment Station personnel working with the Remote Sensing Center. The broad program currently underway includes: investigations on the use of remote sensing for rangeland resource management, wildlife habitat analysis, monitoring natural vegetation in conjunction with urban development, and a program for monitoring seasonal reflectance on a wide variety of rangeland species.

Two important cooperative programs were initiated in 1973 which include: 1) a program with the Soil Conservation Service, USDA on "Remote Sensing for Land Resource Management" and 2) a project with the Agricultural Research Service, USDA, on the effective use of remote sensing techniques for crop condition analysis in conjunction with

cotton insect control programs.

There continues to be an urgency for adapting presently available remote sensing technology for use on agriculture and natural lands of Texas and the nation. Applications programs of the Vegetation Systems Laboratory are designed to interface the highly sophisticated technology of remote sensing with practical problems in several activity areas.

Land Resource Management - A phased program was initiated in 1973 to evaluate selected remote sensing applications for land resource management. An interdisciplinary team composed of scientific personnel from Texas A&M University, and technical personnel from the Soil Conservation Service, USDA, are cooperating to determine the feasibility and cost-effectiveness of certain land inventories using small scale color-IR aerial photography and ERTS-1 imagery for Brazos County, Texas. A formal agreement which activated Phases I and II of this program is detailed in the "Memorandum of Understanding between the Soil Conservation Service, USDA, Texas Agricultural Experiment Station, and Remote Sensing Center, Texas A&M University".

Three tasks are being accomplished by the interdisciplinary team:

1) A study of the relationship between the existing soil survey of Brazos County and interpretations made from color-IR imagery and other remote sensing techniques. Recommendations will be made as to improvements that can be made in the soil survey program by the use of modern remote sensing technology.

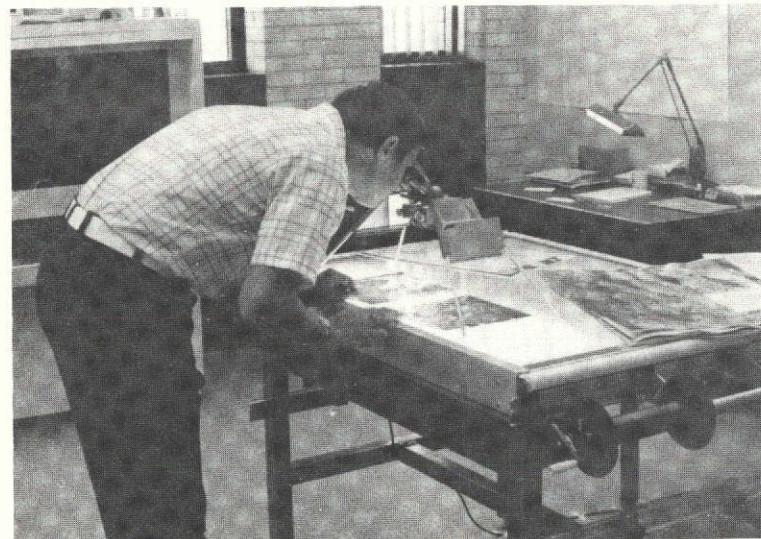
2) An evaluation of color-IR imagery and other remote sensing techniques against conventional methods for conducting a Conservation Needs Inventory (CNI) for Brazos County. Recommendations are to be made for improvements that will expedite collection of CNI data.

3) Development of survey techniques for conducting a wildlife habitat survey on a county-wide basis using small scale imagery.

A phased approach is being employed to expedite the allocation of manpower and resources for conducting several tasks under this investigation. Phase I was concerned with the initial assessment of color-IR aerial photography with respect to feasibility of completing proposed tasks. Results of June and August, 1973 meetings of RSC-SCS personnel indicated that high quality color-IR aerial photog-



*Working group consisting of Remote Sensing Center and Soil Conservation Service Personnel*



*Evaluating aerial photography for delineating ground sampling sites*

rathy at medium to small scales held great potential for completing the outlined tasks. Plans were subsequently formulated for manpower and financial allocations with respect to implementing Phase II of the program. A detailed "Workplan Outline" covering the implementation of the Phase II program was prepared as a part of the Phase I activity.

Emphasis of the Phase II program currently underway is given to field data collection and assessment of NASA obtained aerial photography (1:40,000) taken in late September, 1973. Color aerial photography (1:8,000) was acquired to provide training aids and base maps for field surveys at twenty-four 160-acre sampling sites located throughout Brazos County. Field data was collected by three "task force" teams during the week of October 9-12 by visiting selected sites and employing appropriate ground data sampling methods. A reference document, "Guidelines for Coding Resource and Land Use Data", was prepared to standardize data collection for anticipated computer data summarization.

Ground observations were made of type and condition of land resources and land use at the selected sites. Land classification delineations were inscribed on photographic overlays to be used as training samples for photo

interpretations made from Fall 1973 color-IR aerial photography in a November training session. Adverse weather prevented completion of field surveys, consequently this part of Phase II will be accomplished at the November meeting.

One part of Task 3 under Phase II has been completed. An index of interspersion, intended to reflect habitat potential for white-tailed deer, has been completed for the selected sampling sites. The number of vegetation type changes have been recorded in sampling blocks throughout the county. Interspersion data were acquired along two diagonal lines 0.7 miles long. This parameter will be used as a standard for comparison with other methods for collecting habitat data.

Phase III priorities resulting from Phase I recommendations will be conducted for the entire county. Emphasis would be given in Phase IV to evaluating the potential use of ERTS-1 satellite data for performing or enhancing the task completed in Phase III.

When all phases of the program are completed for the several outlined tasks, the following accomplishments are anticipated:

1. An assessment of the potential use of small-scale, advanced aerial photography for performing the out-

lined task (i.e. Soils Survey, Conservation Needs Inventory, Wildlife Habitat Survey).

2. Estimates of the cost-effectiveness of using advanced aerial photography along with improved photo interpretation techniques for the assessment of land resource parameters.

3. A prototype approach which can serve as an example for further cooperative efforts and the application of remote sensing to other aspects of land resource management.

4. A list of items needing further research to aid in the development of the remote sensing applications.

Cotton Insects - This is a cooperative project between Agricultural Research Service, USDA, and Remote Sensing Center personnel to obtain synoptic information needed in the state-wide effort to control the advance of the bollworm and boll weevil in Texas. Control of cotton insects is a matter of enormous economic significance in Texas. ARS/USDA is conducting a pilot project in Frio County, Texas to determine insect population dynamics and effective eradication methods. It has been determined that timely agricultural land use data are extremely important for effective use of the insect inventory and eradication

techniques. Airborne and ERTS-1 data have been acquired for Frio County test sites in 1973. The ERTS-1 data are being computer processed to isolate and identify crop locations, type, and acreages.

Urban Planning and Land Use - A cooperative agreement with George Mitchell Associates on the "Use of Large-Scale Aerial Photography in Urban Planning" was continued in 1973. The purpose of this study (The Woodlands Project) has been to determine the kinds of information that can be extracted from advanced types of imagery for site planning. Results from the initial phase of the study suggested that a systematic grid sampling technique maximized the information obtainable from high quality, large-scale color-IR aerial photography.

In 1973 the grid sampling procedures were employed to extract specific information about the forest vegetation for an area of approximately 7,000 acres. Parameters are identified by Texas Grid System coordinates for 0.9 acre blocks. All data are assembled in a computer compatible format, summarized and grid system grey maps of the vegetation, terrain and soil features produced.

Vegetation maps including canopy area by forest type, species composition, tree height, and the location of

superior trees are currently being employed by Wallace, McHarg, Roberts and Todd, contractors for site planning. Three types of mapping from the color-IR imagery was found to be of expedient use: 1) Stratification maps of general forest types with legend descriptions for land planning; 2) grid system maps of specific forest features for general site planning; and 3) detailed maps of critical plant communities for detailed site planning.

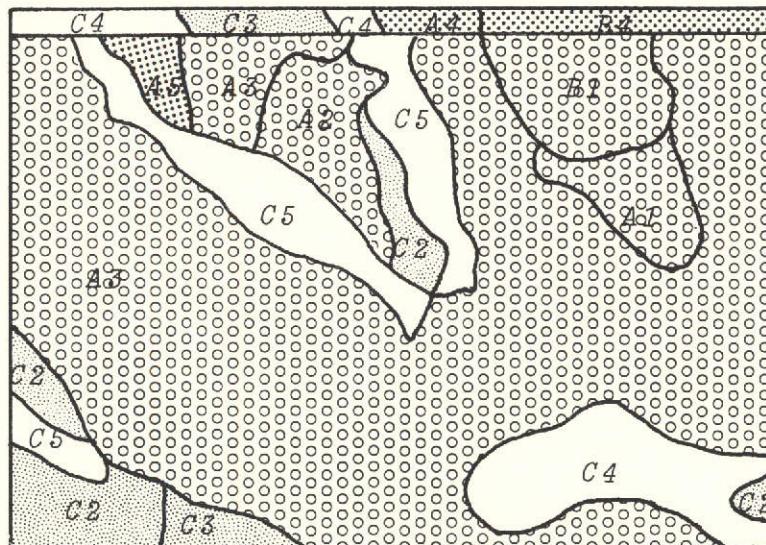
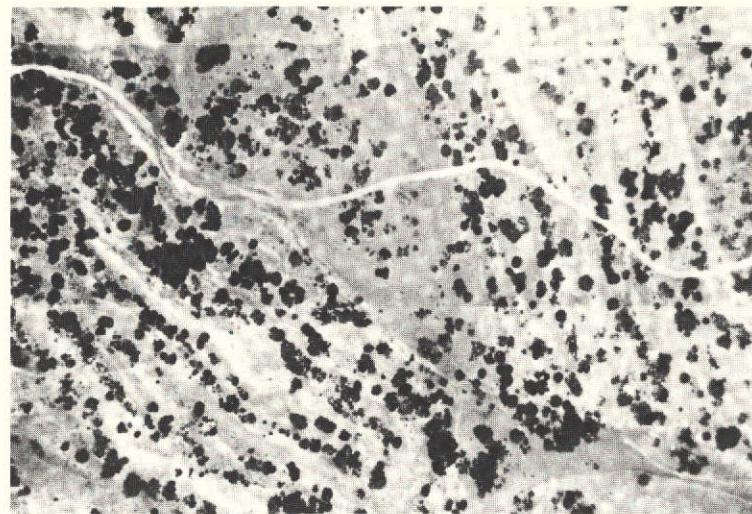
This program is currently being expanded to include the development of a monitoring system that would accurately measure the environmental alterations imposed by the urban development process. Color-IR aerial photography and other sensors will be employed to periodically survey the 18,000 acre development site to record changes in natural vegetation and to analyze the impact of urbanization on the natural environment. These studies will incorporate investigations into the feasibility of automatic data assembly and computer analysis.

A cooperative endeavor with the College of Architecture has been established to aid in determining the essential parameters in application of remote sensing to urban planning. Mr. Jack Wolfe, Department of Urban Planning, was employed in September, 1973, to assist in this function.

Currently an exhaustive annotated bibliography on "Remote Sensing Applied to Urban Planning" is being prepared. This research will investigate the application of remote sensing to site planning.

In consort with the expansion of the Woodlands Project, a cooperative endeavor is being formulated with the Texas Real Estate Institute, Department of Agricultural Economics, and the College of Agriculture. Initial plans have been formulated along the lines of the Cornell University land use inventory for New York. This overall project area is associated with activities of the newly formed Inter-agency Council on National Resources and Environment recently established in Texas by Governor Briscoe. This council has a Remote Sensing Task Force as a subgroup which includes Remote Sensing Center personnel in its membership. This state-wide effort is similar to the Arizona activity and is being encouraged by NASA.

Wildlife Habitat Studies - A study by Mr. Kenneth Moore was completed in 1973 on the "Remote detection of Deer Habitat Factors". The investigation conducted at the Sonora Range Research Station near Sonora, Texas, evaluated the use of aerial photography for: 1) extracting vegetation parameters useful for habitat analyses, 2) quantifying



A Cover type graded most desirable, A, to least desirable, C

1 Food type graded most desirable, 1, to least desirable, 5

Suitable for feeding and resting

Suitable for feeding, unsuitable for resting

Suitable for resting, undesirable for feeding

Mostly undesirable

Color IR photograph (reproduced in black and white) showing part of the study area near the Sonora Range Research Station and the resulting cover-food grades and habitat suitability types derived from analysis of the photograph.

measurements of food and cover components of white-tailed deer habitat, and 3) developing a rapid method for characterizing and mapping deer habitat suitability.

The utility of remote sensing for wildlife habitat assessment is very important in West Texas, where white-tailed deer have tremendous economic significance. The investigation has demonstrated the feasibility of measuring the important plant attributes associated with food and cover components of deer habitat using color-IR aerial photography. Methods were established for assessing the suitability of deer habitat based on the desirability of food and cover components. Pastures having extensive, favorable vegetation types were well correlated with high deer density counts.

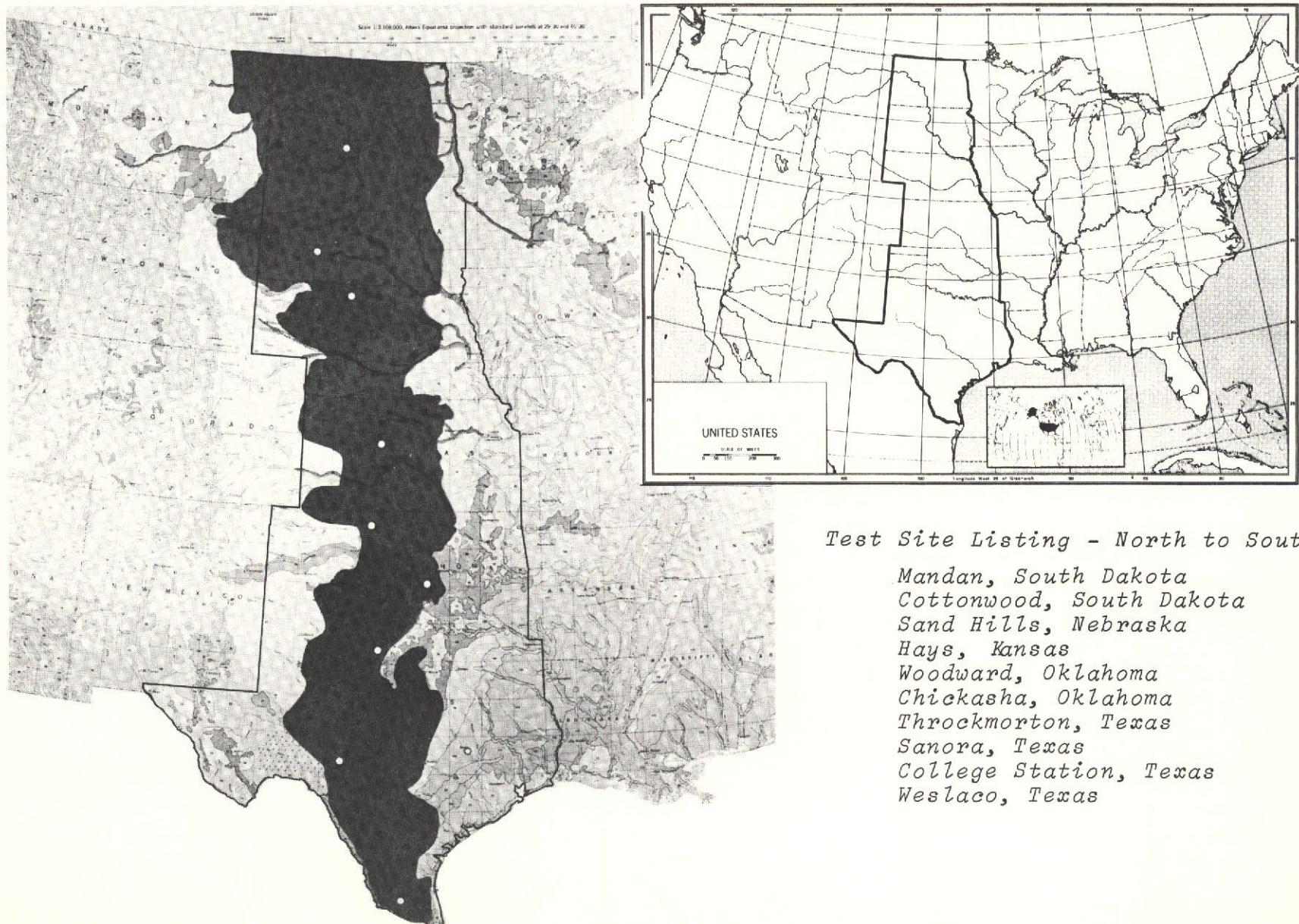
The methods developed from this study illustrate the usefulness of medium to large scale aerial photography for habitat survey. Extension of these procedures to high quality, small scale aerial photography is anticipated. Further investigation is currently underway to use small scale color-IR aerial photography for recognizing food-cover type patterns from broad landscapes.

#### Rangeland Studies

1) ERTS-1 Great Plains Corridor Investigation - Texas A&M University is conducting an ERTS-1 regional

study in which the vernal advancement and retrogradation of natural vegetation (green wave effect) is monitored using ERTS observations throughout the Great Plains Corridor of the central United States. The green wave effect is being charted by employing the relatively homogeneous rangeland vegetation systems of the extensive Mixed Prairie as phenological indicators. ERTS multispectral data and ground observations collected from a network of ten test sites are used to measure vegetation change during the lifetime of ERTS-1. Attention is given to observing seasonal drought and other bioclimatic influences which impact on management and production in agriculture. The overall objective of the investigation is to determine the effectiveness of ERTS-type data for monitoring the vegetation conditions of direct concern to rangeland management and agri-business decisions in the Great Plains.

A network of ten test sites have been established within the Great Plains, extending from south Texas through North Dakota within the Mixed Prairie region. Each site is an established rangeland study area of a state agricultural experiment station or the USDA, and each is monitored by experienced rangeland specialists. The periodic data collected in conjunction with each satellite overpass consists



Great Plains Corridor and test site network

Test Site Listing - North to South

Mandan, South Dakota  
Cottonwood, South Dakota  
Sand Hills, Nebraska  
Hays, Kansas  
Woodward, Oklahoma  
Chickasha, Oklahoma  
Throckmorton, Texas  
Sanora, Texas  
College Station, Texas  
Weslaco, Texas

6/10

of photographs of selected subsites, weather information, percentage green vegetation, standing plant biomass, percentage plant moisture, visually dominant species, and phenology of dominant species. These measurements are compiled and computer processed to form continuously updated site data summary reports graphically portraying the progression of the green wave effect for direct comparison with the ERTS data analysis results. The ground observations acquired to date have documented the annual phases of the vegetation throughout the Great Plains Corridor.

Analyses of black and white imagery suggests that detail in vegetation patterns is much greater than originally anticipated. A preliminary analysis of single band imagery and digital data at locations in the Great Plains Corridor show that woodland, grassland, and cropland areas are easily delineated. Computer derived grey-scale maps from MSS digital data are useful in identifying terrestrial features as well as patterns of natural and cultivated lands which are important in site locations. Single band imagery and digital data have important application for synoptic land use mapping and inventory.

Evaluations of multiband (color composite) imagery shows the expected enhancement of detail and information

content of ERTS MSS data. The use of multiband imagery greatly improves the value of MSS imagery for applications requiring synoptic land use mapping. First order evaluations of vegetation condition and condition changes are possible using color composite imagery. Quality control in processing of the color composites limits these imagery for quantitative determinations.

Statistical evaluation of MSS digital data suggest that the coefficient of variation (CV) for Band 5 mean reflectance data is useful in determining the homogeneity of a vegetative scene. CV's ranged from about 5% for uniform grassland to more than 20% for woodland-grassland areas with variable ground cover. The relatively low CV value for a unifrom scene appears also to be indicative of a desirable signal-to-noise ratio, enhancing the potential usefulness of the data for quantitative "signature" analysis.

Initial ratio analysis, using Band 5 and Band 7 data, suggests the applicability of these data for the detection of temporal changes in the "greenness" of a vegetative scene. The Transformed Vegetation Index (TVI) derived from the Band 5 and Band 7 data, is well correlated with yield of above ground green biomass, which is an indicator

of range forage conditions. Significant shifts in total reflectance from Fall to Winter and from Winter to Spring are an apparent result of a changed solar angle and indicates the necessity of data normalization if used without correction. A solar-angle model has been implemented and tested. All digital data are currently corrected for solar angle declination.

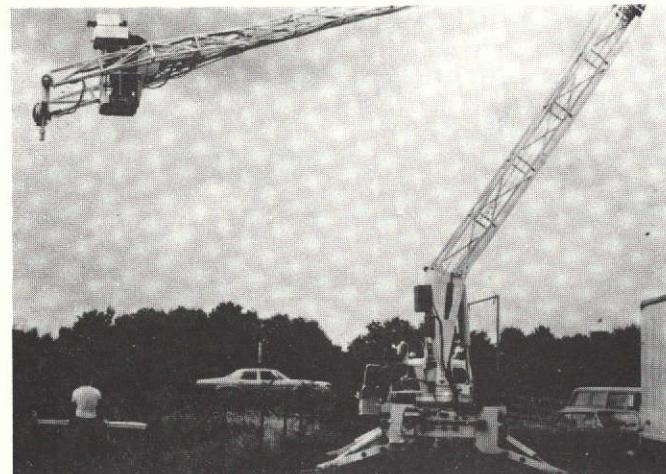
The Great Plains Corridor study has shown significant progress toward realization of an information source directly applicable to preparing range forage condition indexes and reports on seasonal development supportive of rangeland and dryland farming activities: Regionalization of this investigation would provide a unique opportunity to assess the usefulness of ERTS parameters to the important livestock industries of the Great Plains states.

The Texas A&M University involvement in this project and in the ERTS Phenology Satellite Experiment has become well known throughout Texas. This fact, coupled with the published information that the Remote Sensing Center maintains a NOAA Browse File of ERTS-1 data, has led to several instances where various users have sought assistance in employing ERTS-1 measurements.

2) Field Signature Acquisition - During the period of this report a cooperative effort was established with NASA/JSC to obtain field signatures of rangeland species using the Field Signature Acquisition System (FSAS). Grass reflectance characteristics of rangeland vegetation scenes were obtained at test site locations near College Station during the 1973 growing season. The measurements will serve to evaluate the temporal reflectance changes for rangeland vegetation.

The primary objective of this endeavor is fundamental information about the reflectance characteristics of natural vegetation. Two studies are underway to obtain information on: a) the simulated grazing effect, and b) the integration of reflectance components for a grassland community. Field plots were established and initial data collected. Periodic measurements were made during the 1973 growing season to characterize the phenophase dependent vegetation changes. Data reduction and analyses are currently underway.

3) Monitoring Rangeland Improvement - A cooperative project between the Range Science Department and Texas A&M University Research and Extension Center at Chillicothe-Vernon was initiated in 1973 to monitor ecological changes following the control of mesquite. Mesquite



*Measurements of controlled range sites using the NASA/JSC Visible Infrared Interferometer Spectrometer*



*Obtaining ground truth of the controlled range sites during visible and near IR reflectance measurements*

is a noxious woody plant that plagues much of the ranching industry of Texas and the southwest USA. This project is funded in part by a grant from the Waggoner Ranch Estate.

Remote sensing is being applied in: a) monitoring the impact of different brush control treatments on patterns of vegetation succession, and b) determining the effective duration and economic benefits of alternative brush control methods. The primary goal of this investigation is to obtain a basic understanding of the cost-effectiveness of different brush control methods for rangeland production.

#### B. Environmental Monitoring

The primary emphasis of the Environmental Monitoring Laboratory program is on the application of remote sensing techniques to water quality determination. This concentration on water quality is supportive of several related programs at Texas A&M University, including the Sea Grant Program, Water Resources Institute, the Environmental Engineering Division of Civil Engineering, among others.

The program has been structured to concentrate on two application areas. The first area relates to the Federal Water Pollution Control Act of 1972, specifically the Clean Lakes Section. This work is supportive of Texas

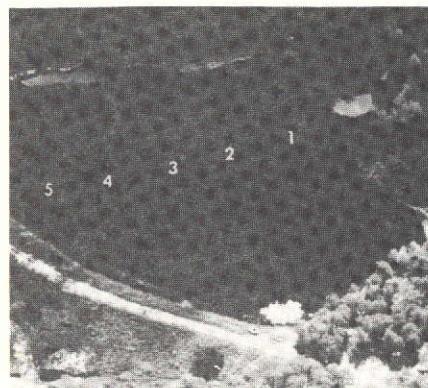
Water Quality Board activities. The second area deals with the environmental impact of dredging and other sediment disturbances along the Texas coast. This work is supportive of Corps of Engineers activities.

Fresh Water Lakes Project - The Federal Water Pollution Control Act requires that the states classify all of their publicly owned lakes according to eutropic condition. Texas has 2200 square miles of bays and estuaries, 80,000 miles of rivers and streams, and over 200 lakes. The extensive task of examining these waterways is the responsibility of the Texas Water Quality Board. The objective of this Remote Sensing Center project is to develop remote sensing techniques capable of rapid, synoptic determination of turbidity and chlorophyll content of fresh water lakes.

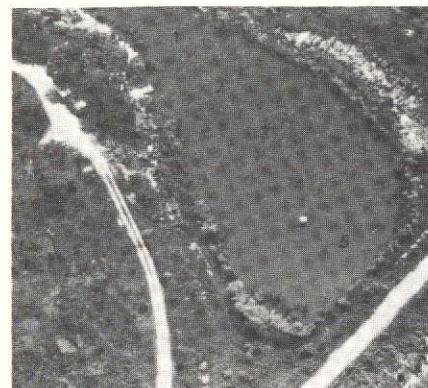
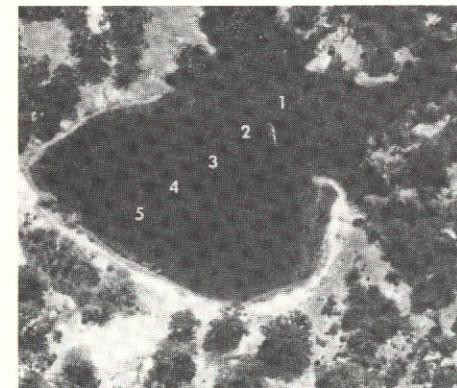
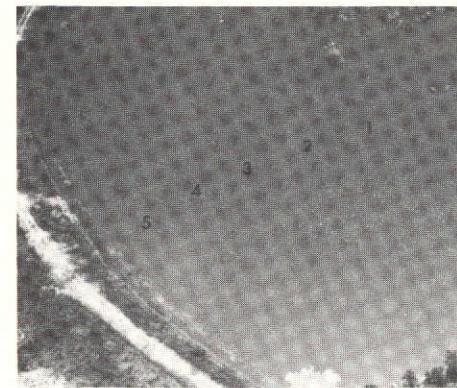
The project consists of two phases, each including several tasks. The first phase involves a field test program to assist in development of an effective means of determining the eutropic condition of lakes. The second phase deals with the acquisition and analysis of ERTS-1 MSS data for fresh water bodies in Texas.

As part of the first phase effort, six lakes in the College Station, Texas area have been under examination for over a year. The lakes provide a wide range of turbidity

COLOR IR



COLOR



Color IR and normal photography of three of the six test ponds each with different turbidity. Density differences between the photograph pairs indicate variations in turbidity between the ponds. Numbers correspond to ground sampling points.

levels (5-340 JTU) and chlorophyll conditions. An air-borne multi-band camera system was employed for remote monitoring of the lakes. This sensing technique was selected because it offers the most versatile approach consistent with the needs of the Texas Water Quality Board for a low-cost, simple monitoring system. Three 35 mm cameras were used for the initial study. Later studies employed two 70 mm Hasselblad cameras. All photography was recorded at oblique angles to reduce the effect of specular scatter due to direct solar radiation.

A series of 14 flights over the six lakes was conducted. Each overflight was accompanied by a ground team that collected water samples for laboratory analysis of turbidity and chlorophyll. The photographic films were analyzed by recording the film densities using a Macbeth densitometer (Model TD-504) in each of the spectral bands obtained.

The results established that turbidity levels could be measured remotely with a high degree of accuracy. The optimum procedure was found to be the use of two different film-filter combinations on two ranges of turbidity. That is, relatively clear lakes having turbidity measurements of 35 JTU or less, required a different technique than for highly turbid water, to obtain good measurement accuracy.

The optimum sensor response to turbidity was found to occur in the red band of color infrared film for highly turbid lakes, and in the green band of normal color film for relatively clear lakes. The data indicate that the following relationship existed between film density readings and turbidity:

$$T = a_0 + a_1 (\gamma)$$

where:

T = turbidity level (JTU units)

$\gamma$  = corrected film density

$a_0$ ,  $a_1$  = constants

The corrected film density,  $\gamma$ , is the density of the red band or green band, depending upon the turbidity range, referenced to a "gray" calibration card. The constants,  $a_0$  and  $a_1$ , are determined from a linear least square analysis of the data. A stepwise regression analysis was utilized to determine the correlation coefficients relating film density and turbidity. The results indicate a 0.975 correlation for turbidity levels above 35 JTU, and 0.922 for levels below 35 JTU.

The procedure employed in an attempt to measure chlorophyll content was to measure the reflectance of the

lakes in two spectral bands using panchromatic film. The bands selected represented the regions of maximum and minimum absorption of light by chlorophyll. The initial results of this work were unsatisfactory, primarily because of the masking effect of the total turbidity of the lakes. The lakes used for the study exhibited a high turbidity to chlorophyll content ratio, hence, were not ideal for such testing. The activity will be continued using narrower passband filters and lakes exhibiting a wider range of chlorophyll concentrations.

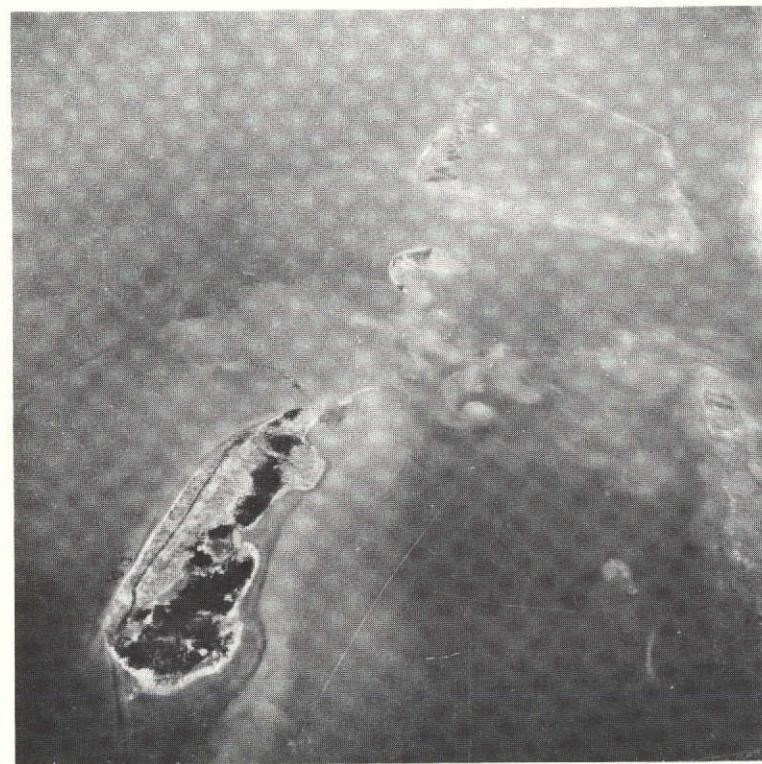
The second phase of the study has resulted in the acquisition of ERTS-1 MSS images for major segments of Texas and the Texas Gulf Coast. Initial analysis of the MSS CCT data indicates sensitivity to the varying optical properties of the lakes due to differing color, turbidity, and chlorophyll concentrations. The data are being used to classify the lakes in Texas according to their ERTS-1 spectral reflectance parameters and to relate these classes to the characteristics of the lakes, including flushing rates, inflow waters, and drainage basin parameters.

Coastal Waters Project - The Texas Gulf Coast includes almost 2000 miles of shoreline extending from the Sabine River on the east to the Rio Grande River on the

south. About 1500 miles of this coastline fronts on bays and estuaries which possess dynamic water properties as a result of human activities. This project deals with two broad areas of concern in the coastal zone: (1) industrial and waste water pollution of the bays and estuaries, with particular emphasis on biological effects; and (2) natural and induced sediment movement.

The sediment problem is one of major economic concern because of the need to conduct extensive dredging activities in the area of the Texas Coast shipping ports. During any single year, it is necessary to dredge over a 150 million cubic yards of material to maintain navigable channel depths for shipping. Dredging is conducted extensively for sand and gravel mining and for land fill associated with urban shoreline development. Over 1000 million tons of material are dredged each year for these purposes.

All dredging activities effect the natural environment to some degree, and recent public reaction to this potential threat to ecological balances has forced discontinuation of several major dredging projects along the Texas coast. The environmental problem arises from the fact that the material that drifts away from the dredge site constitutes a waste discharge having adverse effects on water quality. The extent and severity of this effect is deter-



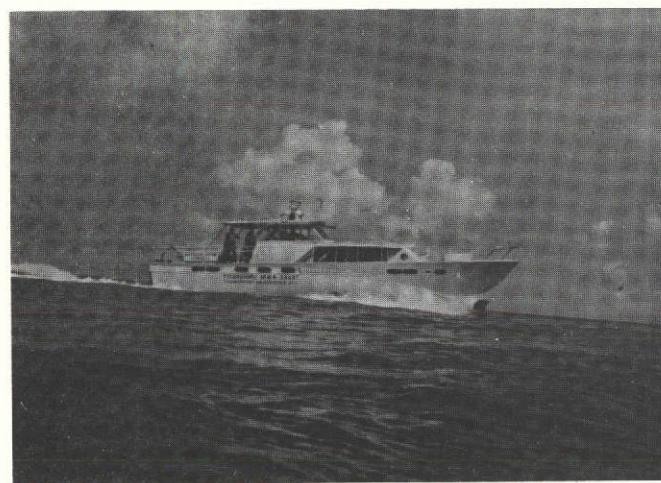
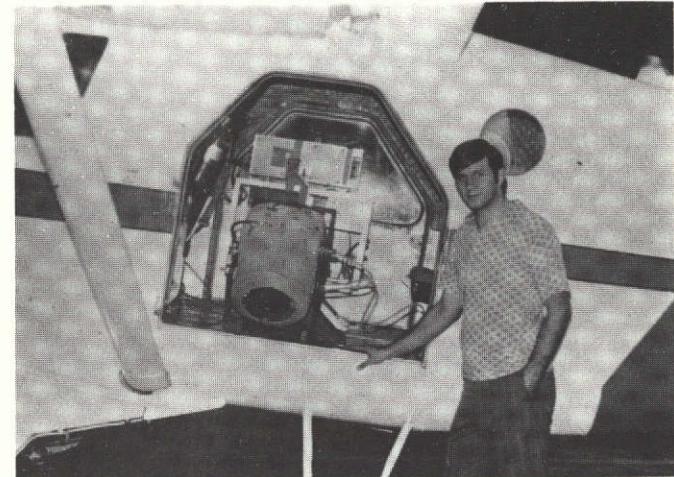
*Sediment generated by dredging operations in Galveston Bay*

mined by a number of factors, including local wave, wind, and current conditions.

The objectives of this study are to document the physical changes that take place in the dredge spoil disposal areas in Galveston Bay due to environmental forces, and to develop the aerial photographic methodology for monitoring dredge spoil disposal methods. This study is a joint project conducted in cooperation with an ongoing Sea Grant Project called "A Study of Dredge Spoil Dispersion in Galveston Bay", and the Corps of Engineers. Results of this study are necessary to assess the contribution that spoil disposal areas have on the pollution load in an estuarine system.

This study is a logical extension of the fresh water lakes projects in that nearly the same procedures can be utilized to estimate the turbidity levels above ambient. The Remote Sensing Center has conducted four photographic flights over Galveston Bay dredge spoil disposal sites. These flights were flown to determine the current velocities and dispersion coefficients from dye releases in the disposal area. The photography was taken with two Hasselblad cameras and a mapping camera using color, color IR, and black and white film. The areas of influence and turbidity levels can be accurately mapped

*Modified DeHaviland  
Beaver and partial  
camera package*



*Texas A&M University  
boat used to obtain  
water samples*

from this photography.

Industrial and waste water pollution is a serious problem in Texas bays and estuaries. In addition to pollutants carried into these areas by fresh water streams, the coastal bays and estuaries tend to attract industrial activity and population centers, along with their resulting waste products. This complex system is often the most biological variable and most productive area in the marine environment.

As the population and industrial development increase, the degree of waste treatment, and control over waste disposal practices must also increase in order to maintain the environment quality at an acceptable level. Along the Texas coast, the Port Arthur complex, Houston, and Corpus Christi areas, particularly, show degradation of water quality.

The purpose of this study by the Remote Sensing Center is to demonstrate to the Texas Water Quality Board how remote sensing can be utilized to document and measure water quality in the large estuarine systems along the Texas Coast. The general appearance of the water can be permanently recorded and the color and turbidity quantitatively measured. The amount and type of suspended and colloidal material in the water column can change light scattering

and absorbing properties of the waterbody and in many cases can be measured by remote methods. The specific objective of this study is to relate the water quality parameters of color, light transmittance, and turbidity to aerial photographic and multispectral scanning imagery.

Two study sites were selected to include a full range of water quality. The sites were: Galveston Bay and Houston Ship Channel, and Corpus Christi Bay and Ship Channel.

An overflight of Galveston Bay was conducted in August, 1973 at 15,000 ft. using the NASA/JSC C130 B aircraft with the 24-channel digital scanner and two RC-8 cameras loaded with color and color IR film. At the time of the overflight a water quality survey vessel collected water samples for laboratory measurement of turbidity, color, and light transmittance. Because of the problems involved in coordinating the NASA aircraft and a ground truth boat during favorable weather conditions, the Corpus Christi Bay flight has not been completed. Field studies have been attempted on three occasions but were not completed due to bad weather.

Urban Planning Project - The Remote Sensing Center is cooperating in a study being conducted by personnel of

the College of Architecture and Environmental Design. The objective of this study is to develop a comprehensive city plan for Madisonville, Texas. The Madisonville Comprehensive Plan will serve both as a model for the accomplishment of future plans and as a mechanism which will guide the growth and development of the city of Madisonville over the next twenty years. The key value of the work, however, is not the accomplishment of the plan but the initiation of the process of planning in the city itself. If this process can be established on a continuous basis, then the study will have made a substantial contribution toward the city's betterment.

The evaluation of the techniques being used in accomplishing the Madisonville Plan will form the basis for an analysis of the merit of the "701" type plan outlined in the Housing Act of 1954. The use of the techniques of photogrammetry and symapping will provide a basis for evaluating the usefulness of these tools for planning purposes.

The comprehensive city plan is a document which analyzes the present condition of the city and projects its physical, economic, social, and political future. The plan is one of the by-products of an integrated community planning process. The plan examines in detail the community's: goals

and objectives, economic base and population characteristics, land use distribution, housing, circulation patterns and transportation systems, community facilities and utilities, capital and financial arrangements, and administrative controls.

There is in existence today a wide variety of comprehensive plans that have been prepared for cities across the United States. Most of these plans have been prepared under the "701" program of the Housing Act of 1954 and are similar in structure and content. These plans can serve as guides for the accomplishment of new plans. Along with these guides are a number of new techniques and mechanisms which have not yet been extensively applied to the formulation of a comprehensive plan. Some of these which will be incorporated into the Madisonville Plan are: a) computer mapping (symapping) - a technique for using the computer to construct maps (This case study will determine which of the traditional planning maps may more quickly and clearly be accomplished by symapping), b) photogrammetry - air photos will be employed for a variety of uses, including, but not limited to the analysis of: spatial distribution of structures, geological interpretation of land suitability classes, and circulation patterns and traffic flow problems.

The method of research that will be used in this study incorporates the following:

- a) Synthesis of goals and objectives from community values,
- b) Formulation of community standards,
- c) Analysis of opportunity and constraint areas,
- d) Administration of questionnaires,
- e) Accomplishment of detailed land use, condition of structures and housing surveys, and
- f) Evaluation of the traditional planning methods of collecting data, analyzing results and formulating the conclusions and recommendations of the comprehensive plan.

#### C. Plant Protection

The Plant Protection Laboratory program concentrates on remote sensing applications to disease management in crop production systems. The emphasis is on virus diseases, including Maize Dwarf Mosaic Virus in corn, sorghum, and millet; Wheat Streak Mosaic Virus in wheat; Tungro and Hojo Blanca Viruses in rice and barley, and Yellow Dwarf

Virus in barley, wheat, and oats. In addition, plant stress conditions, such as moisture stress, are being examined to determine characteristic spectral reflectance properties.

St. Augustinegrass, a host for St. Augustine Decline (SAD) Virus, has been employed as a model virus-host combination to study spectral reflectance properties in order to differentiate between healthy and infected plants using remote sensing techniques. This plant was selected for these basic studies because it provides an ideal experimental model, and because St. Augustinegrass is a valuable commercial crop in Texas which is presently under strict quarantine because of an outbreak of the SAD virus. Field testing has established a reliable remote monitoring method that detects SAD in very early stages of development. This technique was to have been implemented by the Texas Department of Agriculture (Quarantine Division) during the Spring of 1973 using NASA sensor aircraft. Unfortunately, the mission could not be conducted, and an effort will be made to schedule the flights in 1974.

The primary activity during the 1972-73 period was devoted to a study of the spectral reflectance characteristics of Maize Dwarf Mosaic Virus (MDMV) in sorghum. Sorghum for grain and forage is one of the principal crops in Texas. Over nine million acres of grain sorghum were

grown in the state in 1971. One of the most important and limiting diseases of this crop is caused by the Maize Dwarf Mosaic Virus. This virus is continuously present in the sorghum growing areas of the Southwest (Texas, Oklahoma, New Mexico and Kansas). The virus overwinters in rhizomes of Johnsongrass, a plant common in the Southwest that emerges prior to seeding the sorghum crop. The disease is transmitted by some 13 species of aphids. Those concerned with controlling the disease need information on (1) its distribution and spread each year, (2) the disease intensity and estimated crop losses, and (3) effects on genetic material for use in the commercial and university breeding programs.

This study was made to first determine in which spectral bands maximum reflectance differences occurred among healthy and MDMV-infected sorghum plants, preliminary to sensor designation for inventorying sorghum infections from the air. Secondly, the study was designed to develop an operational system for aerial detection and estimation of severity of MDMV in sorghum. The research was a cooperative effort of the Department of Plant Sciences and Remote Sensing Center and NASA/JSC, Applied Physics Branch.

Plant material for laboratory and field studies employed mechanically inoculated grain sorghum showing varying levels of disease development. A randomized split

plot design was used in the field trials with healthy controls and MDMV diseased sorghum. The plot size was 20 ft. x 20 ft. and all treatments were replicated four times. Mechanical inoculations were made in the greenhouse and in the field.

Data acquisition included measuring the spectral reflectance of samples in the laboratory using the Cary-14 RI spectrophotometer. The model-14 RI spectrophotometer is designed for automatic recording of energy in the wavelength region of 225 nm to 3,000 nm with good resolving power and high photometric accuracy.

Imagery was obtained on flights during the growing seasons of 1972 and 1973 over the Texas Agricultural Experiment Station farm near College Station, Texas. Flight dates varied because minimum weather conditions of less than 25% cloud cover and minimum haze had to be met for this photographic system to be functional. Time of sensing consistently was between 1100 and 1400 hr. (CDST). Altitudes used were 300 M and 470 M above mean ground level. A Ziess RMK A 15/23 (9" x 9") camera equipped with a Ziess D (D525 nm) cutoff filter was mounted in a modified Dehaviland Beaver aircraft which served as the sensing platform.

Spectral reflectance data from the Cary-14 RI spectrophotometer showed spectral differences between heal-

thy and diseased sorghum. These regions are centered on 450 nm (blue), 525 nm (yellow), 650 nm (red) and 800 nm (infrared) regions.

The aerial imagery was collected 82 days after seeding. Calculation of areas of the fields in each disease rating improved disease severity estimates and predicted values when the densities were assessed to ratings of 1) healthy and vigorous 2) mosaic, slightly diseased 3) mottled, all plants moderately diseased 4) mottled and redleaf and 5) severe redleaf and stunting. These ranges are defined as signatures and were checked for accuracy against field disease ratings. Diseased sorghum was differentiated from healthy sorghum in both 1972 and 1973. Once disease signatures are determined, only spot ground truth may be necessary. Data should be collected as soon after symptoms appear and before maturity, since symptoms become masked in sorghum as the plant approaches maturity.

## V. SUPPORTING TECHNOLOGY

### A. Applied Data Analysis

The application of computer analysis of remote sensor measurements requires multilevel technique and software development. The first level of activity involves research into new analysis techniques or the development of existing techniques to support and prove new applications. Once techniques have been adequately defined and proven for specific applications a second level of activity is required. This level of activity provides for the development of software/hardware systems which make the developed techniques available for utilization by personnel technically trained in computing operations. It is also beneficial if these users of the system are familiar with the specific techniques involved. This level of development is the closest many techniques get to being operational and is generally "procedure development" for applications. There is in addition, however, a third level of activity which is the most applications oriented and ultimately the most beneficial. This level of activity provides for the interface of the developed techniques and procedures into a user oriented-facility for general applications use. It is only after this level of development that a technique can be

considered to be operational and can be integrated into specific applications management programs.

Data Analysis projects are being conducted at each of these levels, however primary emphasis is placed on achieving the last level, that of interfacing techniques directly with applications project personnel.

Arctic Ice Analysis - A significant study has recently been concluded which has correlated NASA 13.3 GHz radar measurements to the age of Arctic ice. The Arctic region has recently attracted considerable attention because of its reserves of mineral resources. Less commonly known, but more dramatic is the effect of the dynamics of the sea ice in the Polar Basin on weather in the Northern Hemisphere. The macroscale heat flow patterns developed in the Arctic due to polynyas and leads in the ice pack, and their movement, is reported to be a major driving function in the hemisphere's weather. The Arctic Ice Dynamics Joint Experiment (AIDJEX), a multi-national research program in the Arctic, is seeking to solve some of the unanswered questions about ice dynamics and its meteorological significance, and ice age distribution is important in these considerations.

The Remote Sensing Center studies were conducted as part of a Naval Ordnance Laboratory supported project,

"Radar Studies of Arctic Ice and Development of a Real-time Arctic Ice Classification System". This study has provided a classical model for the application of remote sensor data analysis to a specific problem of concern. It has involved the theoretical technique development required to provide the analysis tools; the techniques were developed into a software package (SCATPGM) and specific procedures were developed for analysis of the radar data; and finally a hardware system was developed incorporating the essential signal processing ingredients on an operational level. As a result of the systematic application of SCATPGM to the radar data, significant correlations and signature relationship have been identified for Arctic sea ice classes. Additionally, hypothesis concerning the specific microwave scattering mechanisms involved have been formulated and procedures for extension of this work to other terrain types have been investigated.

ERTS-1 Phenology Study Support - A comprehensive analysis package has been developed for operational handling of ERTS MSS data in support of phenology studies being conducted in the Great Plains, Rocky Mountain, and Columbia River Valley regions of the United States. Over twenty individual test sites are involved, and processing of data

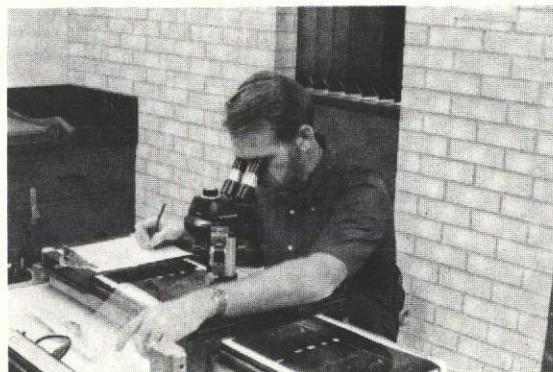
taken over each of these sites for each ERTS overpass constitutes a significant data handling problem. To minimize the processing delay, specific analysis procedures have been developed and standardized for the project. The test sites were located by longitude and latitude. When digital computer compatible tapes arrive from NASA for a test site, a 30 km square centered on the calculated site location, is extracted from the digital tape and stored on high-speed disc storage. A line printer grey-scale map of ERTS Band 5 is printed. This is necessary since the numerical resolution of satellite ground track prohibits a greater location accuracy than 3 km. From the grey-scale printout, individual features are located and test site tape coordinates are determined manually. These coordinates are entered, and the second phase of processing extracts signature mean and covariance information from the image data within the site boundaries. This information is presented in a site processing summary report and is also stored in a disc file for future reference. Additional software packages have been developed to reduce and graph ground data samples collected at each test site.

Due to the large inventory of ERTS imagery and magnetic tapes required to be on hand, a computer cataloging procedure was developed to enter and cross reference the data. An updated catalog is provided periodically referring



*Library of ERTS I data  
tapes containing imagery  
of the Great Plains Cor-  
ridor*

*Gray map printout of ERTS  
I data*



*Comparing ERTS I data of  
the Great Plains Corrid-  
or to aerial photography*

all available ERTS data by ID number and site designation.

Optimized Selection of Real-Time Classification

Processors - With the advent of modern digital technology and advanced development in the production of compact and modular-sized computational units, the classification and analysis of select remote sensor data in real-time became feasible, and highly desirable in many cases. Because of the subjective nature of the classification problem, numerous classification algorithms and techniques can be applied to solve a given problem. The digital realization of various types of classification algorithms requires differing degrees of complexity and computation power. Additionally, each real-time data classification problem imposes its own unique constraints on the class of algorithms to be used, and on the flexibility and complexity of the implementation.

An applied data analysis study has been initiated to survey and evaluate different classification techniques, their trade-off considerations, and the feasibility for their implementation in a real-time application. This study will condense the information obtained into a systematic and step-by-step procedure for the selection of the appropriate classifier and its implementation for real-time processing, based upon specific system and data constraints. Such a

procedure can immensely reduce the task and effort involved in the selection and implementation of various classification techniques for real-time classification problems.

#### B. Data Analysis Facility

A Data Analysis Facility has been established in the Remote Sensing Center to provide an interface between users and remote sensor data. This facility includes a Remote Sensing Data Analysis System incorporating a Texas Instruments 980A minicomputer, the RSC Dynamic Color Display, Analog/Digital-Digital/Analog Conversion capabilities, and various other equipment. Additionally, current examples of remote sensor data, as well as catalog listings of data available in the Remote Sensing Center Data Library are kept in the Facility, along with the Texas A&M-NOAA ERTS Browse file. This Facility has been established to provide the capability for demonstration of remote sensing tools and techniques to the general public, and to provide support for the Center's application projects.

Remote Sensing Data Analysis System - It has been apparent that the analysis techniques and interpretive methodology necessary for applied remote sensing are not generally available in an operational form to individuals and local and regional resource management agencies which might most benefit by their utilization. These techniques have been

vested in groups dedicated to remote sensing, which for the most part are supported by large facilities and equipment capability. It has also been recognized that equipment and facility complexity required for specific applications is significantly less than that required for general purpose support. The effective interface and utilization of remote sensing data by local agencies requires an integrated techniques/hardware/software system. These characteristics are included in the Center's Remote Sensing Data Analysis System which provides simplistic interface between user agency personnel and the developed techniques and available data provided by the field of remote sensing.

Implementation of a prototype analysis system suitable for remote sensing application was undertaken in line with the Remote Sensing Center's goal of direct interfacing with applications groups to provide technical support in the area of remote sensing. General specifications for such a system were outlined and the evolution of the system has begun. Consideration of the constraints existing in the average user agency and the most cost-effective methods for system design within these constraints were paramount in system specification considerations. It has been assumed that user agencies would have a minimal technical capability

for handling the sophisticated data analysis techniques available, and that the utility of these techniques could be made available only through a simplistic, interactive software interface. Hardware configurations should be simple, inexpensive, and should maximize the amount of information available through familiar communications media. As it is developed, this analysis system has been incorporated into specific RSC Application projects, and will be made available for general use through the Remote Sensing Center Data Analysis Facility.

TI980A Minicomputer System - During the year, delivery was taken on a Texas Instruments 980A minicomputer system which included the CPU with 12K words of memory, an ASR-33 teletype with a punched paper tape capability, and a 9 track, 800 bpi, digital magnetic tape drive. This particular minicomputer system was chosen as the nucleus of the Data Analysis System for its computational speed, flexible instruction set, versatile I/O interface capability, and the low cost of the CPU, memory and available peripherals. The TI 980A, is a modern, 16-bit, microprogrammed computer which uses inexpensive, high speed, MOS-semiconductor memory, and has proven to be a cost-effective system component. A magnetic tape drive was purchased to allow system interface with ERTS and other computer compatible tapes, since this

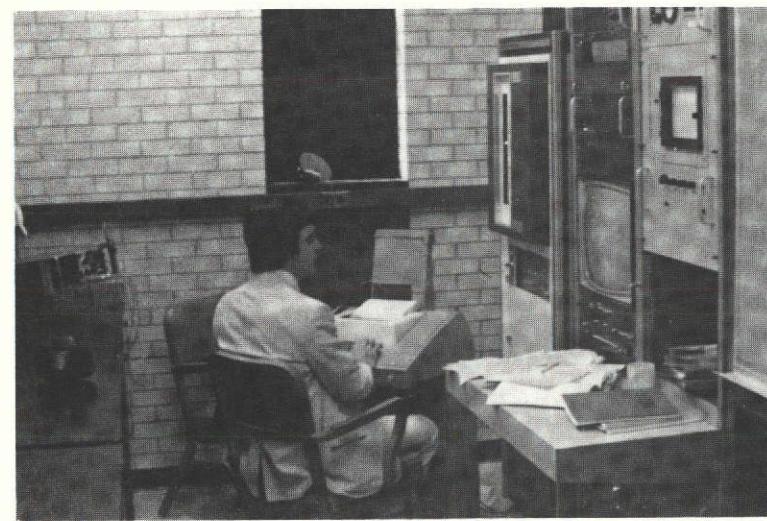
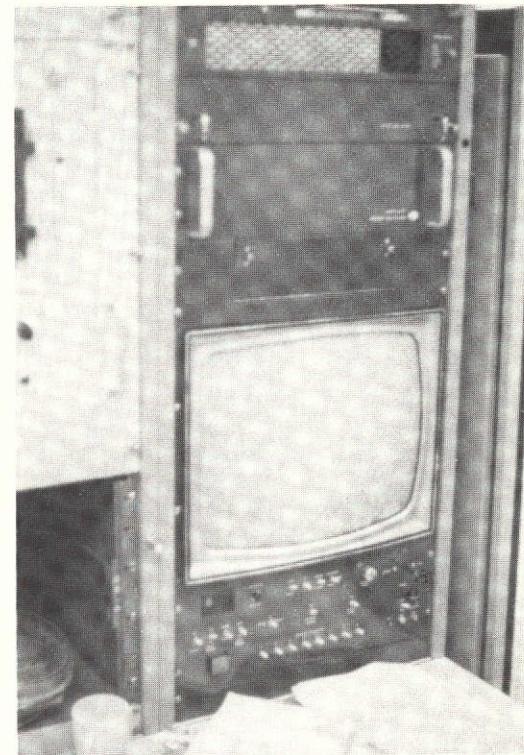
is the media by which the greatest amount of remote sensor data can be conveniently transferred.

Dynamic Color Display - The increasing use of computers for processing, enhancement, and presentation of imagery and spatial relationships has created a need for flexible, high-speed interactive interface between computer data files and the human investigator. This interface has traditionally taken the form of monochromatic CRT display or line printer grey-scale mapping. The use of the monochromatic display has been limited by the amount and variety of data which could effectively be presented through a grey-scale rendition. This limitation has led to the introduction of color displays and has effectively increased the data presentation efficiency of the CRT display.

A totally-digital color image display system, utilizing a standard color television receiver as the display device, has been designed and developed at the Remote Sensing Center. The use of a commercial television receiver insured a low cost display terminal and allows a simplified expansion capability in multiterminal applications.

In addition to the simple display of computer generated or enhanced imagery, this display system has provisions for real-time operator interaction either via the display control panel or over the computer interface. Using

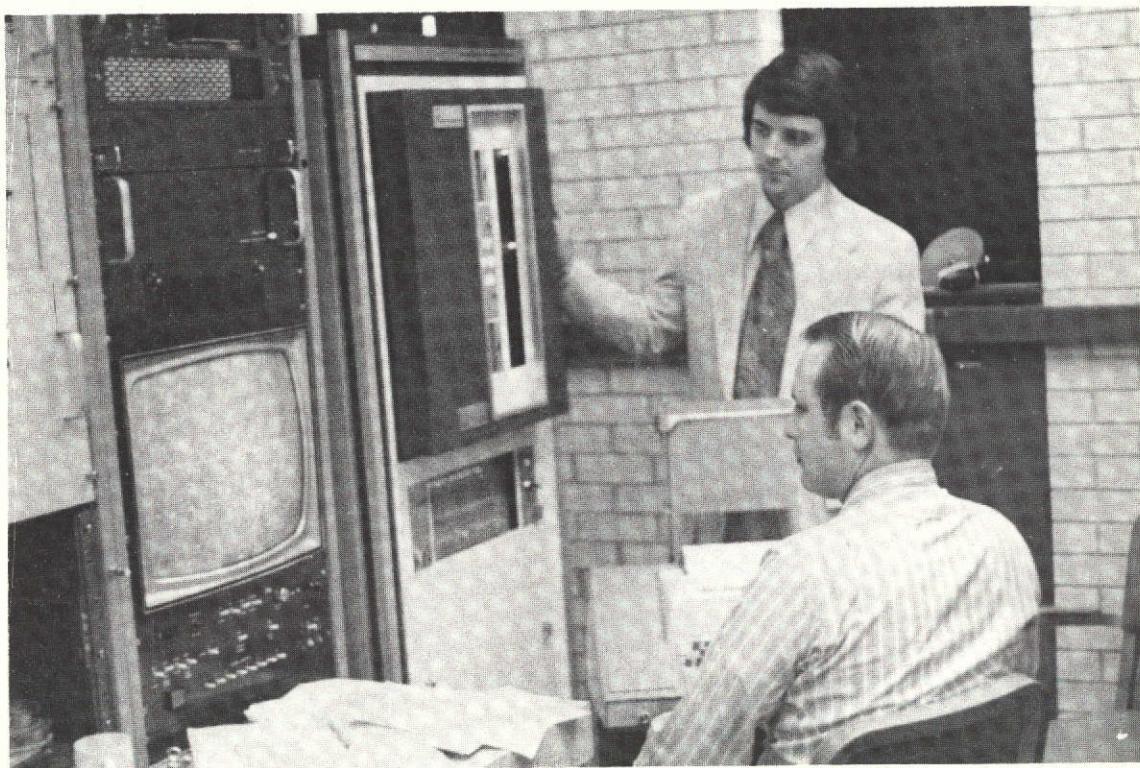
*Dynamic Color CRT Display System*



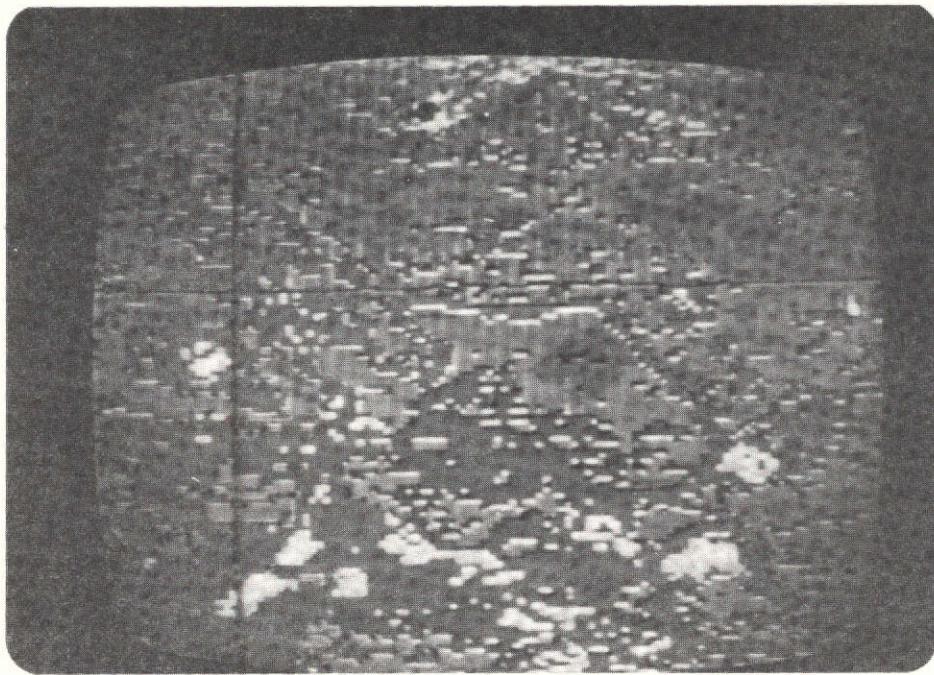
*Operation of the Dynamic Color  
CRT Display System via the TI  
980A mini-computer*

the controls available, the operator can select the color coding of the image, expand selected portions of the screen, or extract data from the screen refresh storage and display the data on a numerical readout. The display has been designed as an independent unit, once data has been transferred, to allow refresh and operator interaction without interfering with other computer functions. The development of the Dynamic Color Display has greatly enhanced the capability of the Center to provide direct applications support to user agencies, and was essential for effective interaction.

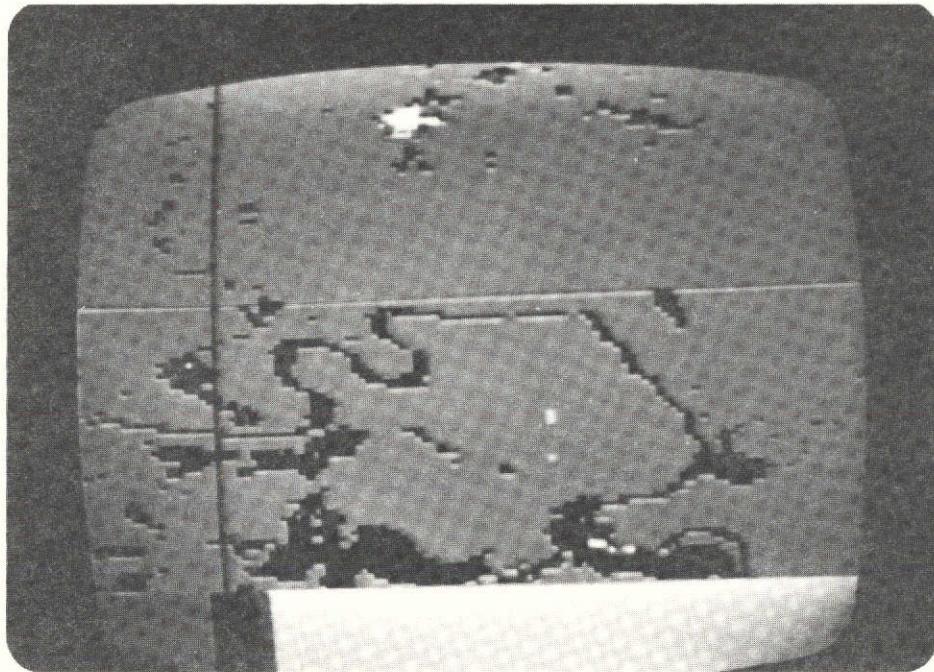
Much of the data available from remote sensor systems is available only in an analog format. To effectively interact with these types of data, an analog/digital conversion system was developed as part of the Data Analysis Facility. This instrumentation will permit the analysis of such analog data as line scanner and radar imagery, and numerous types of along-track measurements. Also developed as part of this package has been a digital/analog interface. This capability will allow interaction with analog display devices, and facilitates simulation of analog sensor measurements for testing of real-time signal analysis processors under development at the Center.



*Analysis of ERTS I data using the Dynamic Color  
CRT Display*



Color reconstruction of ERTS image showing the College Station, Texas area and the Brazos River on the Dynamic Color CRT display



Density slicing of the demonstration image (top image) to enhance the College Station area (top center-white area) and the Brazos River (center and bottom-black area)

System Software - Another major component of the color display system is the software required to interface with the various hardware peripherals providing for maximum interaction with user personnel. The software development has been initiated, and it is this development project which is currently the most active part of the overall system/facility development. A major part of the operating system software will be syntax driven algorithms to parse operator commands and to set the logic required to enable execution of driver and analysis software. This software system concept permits the specification and decoding of simple English statements for operator control. This requirement for simplistic operator interaction is a significant part of the overall system specification, and this particular software approach provides a flexible method for effecting this interface. Another important component of the system software will be the interface and driver software required for management of complex data files. Additional software will be developed to make specific data analysis techniques available to system users.

Browse File - Texas A&M University and the Remote Sensing Center have been designated as an ERTS Browse File Facility for NOAA. On a monthly basis, microfilmed ERTS imagery and data catalogs are received and placed at the

disposal of the general public through the Browse File Facility, which is located in the Remote Sensing Center Data Analysis Facility. All ERTS imagery through May, 1973, and Catalogs through August, 1973, for both U. S. and non-U. S. regions, are currently on file. A microfilm reader has been provided for users of the facility. To date, the greatest use of the Browse File facility has been made by petroleum exploration companies who are obtaining considerable aid by presurvey of prospect areas from ERTS imagery.

### C. Sensor Systems

Development of applications of remote sensing techniques is dependent upon the availability of adequate sensor systems. Photographic and multispectral scanner systems are operational, however other sensor systems, which could greatly expand the information collecting capability within the remote sensing field, are still in various stages of development. Of particular significance in this regard are microwave sensor systems.

The Remote Sensing Center has maintained a leading position in the development of microwave sensing techniques, especially in the important application area of soil moisture monitoring. Recent work with laser systems has led

to development of a new sensing device named a Lidar Polarimeter. This sensor has shown potential for remote monitoring of water quality parameters and oil spills on water.

Microwave Sensing of Soil Moisture - The Micro-wave and Infrared Systems Laboratory projects during this year have continued the microwave sensing studies in progress for several years. This work has led to significant advances in the development of theoretical models and the acquisition and analysis of microwave measurements. The effort has been accelerated in 1973 as a result of a cooperative project with the Johnson Space Center. JSC has assembled a two-frequency passive microwave radiometer mounted on a "cherry-picker" truck. The availability of this L-band/X-band sensor permitted detailed studies of microwave emission from controlled field test sites in support of model development. Experiments using multiple frequency airborne microwave sensors over documented sites at Weslaco, Texas, and Chickasha, Oklahoma were also conducted in 1973.

The test area near Chickasha, Oklahoma, is part of a watershed research area under study by the Southern Plains Watershed Research Center (USDA/ARS). The studies

include determination of downstream runoff, sediment flow, and ground-water levels relative to implementation of flood control measures. The site consists of eleven subsites on two separate flight lines. The subsites vary in length between 200 and 1200 meters. The dominant soil types are Reinach silt loam and McLain silty clay loam. ARS field teams collected multiple soil samples from all sites to a depth of 10 cm. Soil composition and moisture content were determined for all samples. Laboratory waveguide measurements of the complex dielectric constant of the samples were made at Texas A&M University.

The Chickasha area was overflowed by the NASA CV-990 aircraft equipped with nine microwave radiometers. Three of these (1.42 GHz, 19.4 GHz, and 37.0 GHz) provided data suitable for analysis. At the time of the overflight the test area soils were relatively dry (average moisture content of 10 percent), and a moderate vegetation cover was present on most fields.

The Weslaco, Texas site is an established NASA Test Site operated by the USDA/ARS and has been the location of previous soil moisture monitoring experiments conducted by the Remote Sensing Center. The site consists of a 29 kilometer long section of agricultural fields. The predominant soil is Harlingen clay. At the time of the overflight, approximately half of the fields were plowed bare ground. The

remainder supported corn, sorghum, and vegetables in various stages of development. The entire area was saturated due to heavy rains preceding the flight.

Analysis of the Chickasha microwave emission data showed two major features: first, the microwave brightness temperatures measurements of fields having moisture content of less than 15 percent did not correlate with soil moisture, and second, the presence of vegetation adversely affected the interpretation of the results. However, an analysis of both the Chickasha and Weslaco measurements established a linear relationship between soil moistures and microwave emission of  $-2.15^{\circ}\text{K}/\text{percent moisture}$  at 1.42 GHz, which is in good agreement with previous results.

One of the most significant results of the experiment was the identification of the effect of vegetation on the microwave measurements. Subsequently, a project was developed to examine this effect. In this work, models were developed for the apparent microwave temperature and radar backscatter coefficient of vegetated terrain to illustrate the effects of vegetation on the sensitivity of these parameters to variations of soil moisture. Three types of terrain are simulated for both the passive and the active case: a uniform canopy over a smooth surface, plant rows on a smooth surface, and plant rows on a rough surface.

In each case the canopy is defined by its overall dimensions and by its electric permittivity, which is determined from the Weiner model for dielectric mixture. Emission and scattering from both the soil and the canopy were considered, but atmospheric effects were neglected.

The expression developed for the apparent temperature of vegetated terrain includes terms for the apparent temperature of the bare soil and of the canopy. The bare soil term is modified by an exponential term to account for attenuation of radiation from the soil by the canopy. The term which represents radiation by the canopy assumes that the canopy is a homogeneous layer. The expression for the apparent temperature of row crops is the average of the apparent temperatures of covered or shadowed soil and visible bare soil. A rough surface is represented by a surface roughness factor and a coefficient of effective area of specular refraction.

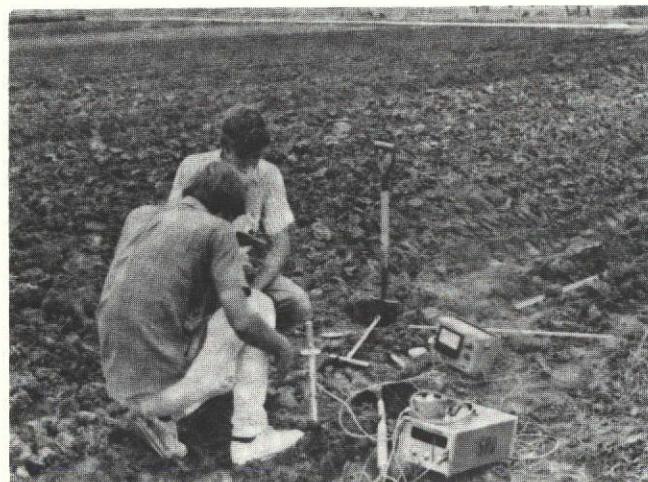
The expression developed for the backscatter coefficient of vegetated terrain is similar to the expression for apparent temperature. The term for backscatter from smooth, bare soil is determined by the physical optics method. The term for backscatter from the canopy is a modified form of a model for scattering from long, thin dielectric cylinders.

Calculated data indicate that the sensitivity of the apparent temperature and backscatter coefficient to variations of soil moisture, decreases as the amount of vegetation increases. It is shown that the same effect results from increasing signal frequency or angle of incidence.

These studies established a foundation for a series of ground-based microwave measurements designed to verify the basic models. The NASA two-frequency (L-band and X-band) passive microwave system was used to measure emission from field plots exhibiting three stages of surface roughness on a uniform soil type. The plots were irrigated to produce a wide range of soil moisture conditions. The initial data were recorded for bare soil, then the plots were planted with a uniform vegetation, and all measurements were repeated. The data are in the process of being reduced and analyzed for comparison with the model predictions.

Laser Sensing of Polluted Water - Theoretical rough-surface scattering theory developments during the 1972 program suggested that a dual-polarization laser-backscatter system (Lidar Polarimeter) should be capable of unambiguous polarization ratio measurements of subsurface scatter. In 1972, a small 5 mw helium-neon laser system ( $\lambda = 633\text{nm}$ ) was

*Measuring the Microwave emission of bare soil using the NASA/JSC Microwave Signature Acquisition System to determine effects of soil moisture and surface roughness*



*Obtaining soil moisture and temperature profiles of the bare soil plots during the microwave experiments*

designed, constructed, and used to study the feasibility of active remote water quality monitoring based on polarization ratio measurements. The results of the study showed a relationship between incident beam diameter and absolute impurity concentrations. The study also showed the signal-to-noise ratio feasibility of very low power systems for daylight operation at slant ranges in excess of 30 meters, and for a low altitude airborne system with moderate laser power.

In 1973, additional laboratory studies were conducted to further verify that subsurface contaminant concentrations were related to the Lidar Polarimeter measurements. The rough surface scattering theory was extended and good agreement with the theory was obtained in laboratory measurements of both smooth and rough surface targets.

A second generation, field-portable Lidar Polarimeter instrument was designed and constructed based upon the experience gained in the laboratory studies. This instrument has been used for field studies on the Brazos River and the Houston Ship Channel. Comparison of the results of laboratory analysis of water samples and the Lidar Polarimeter field data indicates excellent correlation

between standard side-scattering nephelometer turbidity and the laser backscatter measurements. The Lidar Polarimeter has been operated from atop bridges and from the deck of a moving research vessel, and provided rapid, accurate recordings of turbidity.

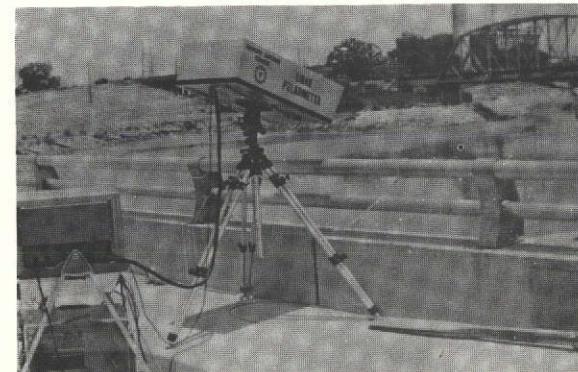
As a result of the success of testing with the monochromatic Lidar Polarimeter, a dual-wavelength system has been designed for detection of oil spills on water. The two-frequency (633 nm, 442 nm) concept is being employed to enhance the detectability of a wide range of petroleum products. This work, funded by the Coast Guard, will provide a prototype system of a field sensor capable of continuous monitoring of natural waterways.

The extension of the rough surface scattering theory and associated laboratory measurements was developed around previous studies of the Kirchhoff (physical optics) approach conducted by the Remote Sensing Center. The emphasis in this work has been on obtaining a description of the depolarization of incident electromagnetic waves due to subsurface volume scatter. The theoretical study included polarized and depolarized components contributed by both the surface and subsurface scatterers. In order to investigate the validity of the assumptions concerning the physical phenomenon utilized in the theoretical development, a series of

LIDAR Polarimeter designed  
and constructed at the  
Remote Sensing Center



Experimental measurements  
of the Houston Ship Chan-  
nel (above) and the Brazos  
River (right) to determine  
the feasibility of remote-  
ly detecting surface oil  
and measuring water qual-  
ity



dual polarization laser backscatter measurements of rough surfaces exhibiting a volume scattering process were performed. The experiment utilized both smooth turbid water and cast dielectric samples. The turbid solutions investigated were composed of a high concentration of scatterers and absorbing material to control the amount of volume scatter. The dielectric samples were pigmented to vary the amount of volume scatter from a negligible amount to a level where the surface scatter was negligible. Also the surface roughness of the samples was varied from a very rough to a moderately rough surface. Using these targets, polarized and depolarized backscatter measurements were recorded using both horizontal and vertical transmit polarization for angles of incidence between  $0^\circ$  and  $70^\circ$  from nadir.

The experiment with water showed that the subsurface depolarization mechanism was dependent on both the number density of particles suspended in the medium and the concentration of dye dissolved in the medium. Also, it indicated that multiple scattering within the turbid water provides the primary contribution to the depolarized backscatter for spherical particles.

The data obtained using cast dielectric targets varied from a polarization ratio of approximately unity to a minimum below the sensitivity of the system. A

surface-dependent depolarized return was measured for very rough, non-volume scatter (black) samples which was not present for the smoothest black sample. However, this term was insignificant in contrast to the strong volume scatter samples. The depolarized volume scatter is independent of the surface roughness for incidence angles less than 55°. Also, reciprocity is valid for the depolarization mechanism.

In order to examine the validity of the theoretical development, calculated values from the theory were compared to the experimental data. The results of this indicated that the calculated values and the experimental values had correlation coefficients greater than 90% for most of the data. Therefore, the physical and mathematical approximations utilized in the theoretical analysis appear to be valid.

Photographic Sensing - The Remote Sensing Center utilizes two aircraft at Texas A&M University to conduct photographic sensing missions. These modified DeHaviland Beaver aircraft are equipped with a variety of camera systems, including a Ziess RMK A 15/23 (9" x 9") camera. A multiband camera system has been installed in one of the Beaver aircraft. The camera system consists of two 20 mm Hasselblad

cameras and one K-17 mapping camera. The cameras are presently mounted to take oblique pictures for water quality studies. The mapping camera takes a picture that extends from the nadir to the horizon. In most cases, the photos can be taken to include shoreline with sufficient horizontal control for photographic orientation. The three cameras have been timed to take simultaneous pictures so that the orientation matrix for the mapping camera can also be utilized for the 70 mm cameras.

A photographic film processing laboratory is being organized to process aerial film. Most of the equipment for the darkroom has been acquired, and the Center is in the process of modifying existing laboratory space for a darkroom. The facility will enable processing of both color and black and white film up to 9 1/2 inches wide. The processing equipment now in use include a Morse B-5 rewind film processor, Nikon 70 mm film processor with 100-ft. reel, Kindermann, 70 mm film processor with 15-ft. reel, film dryer, contact printer, print dryer, sinks and other minor equipment have been acquired for the facility.

A Macbeth transmission densitometer model TD-504 was acquired by the Center to quantitatively evaluate the light return from objects with aerial photography. The

densitometer has a digital readout and is equipped with three color filters and a visual filter for density measurements within a range of 0 to 4.0.

#### D. Signal Processing

The problem of handling the enormous data volume associated with many remote sensing applications has motivated research into numerous data reduction processes. The Remote Sensing Center is participating in development of improved procedures for computer processing of multivariate data, but is also very active in developing new real-time signal processing systems. The potential for remote sensing data reduction at the sensor output is considerable, and it has been found that the desired information product can often be obtained directly from the electrical signal output of the sensor in real-time. The Center has developed signal processing systems for three specific remote sensing applications: remote identification of Arctic sea ice; remote turbulent air velocity measurements; and remote monitoring of water quality.

Radar Signal Processor - Activities in the area of real-time radar signal processing and analysis were conducted by the Remote Sensing Center under support of the

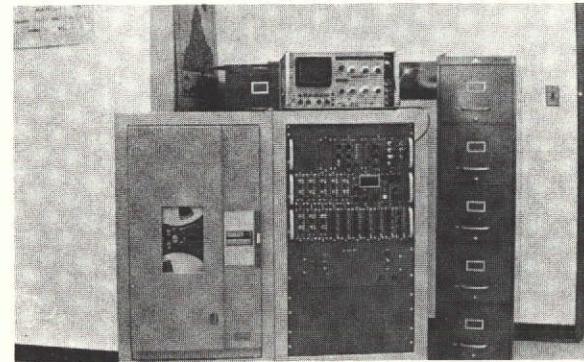
Naval Ordnance Laboratory. This program included development of a laboratory prototype processor system for concurrent use with data obtained by the Ryan 13.3 GHz Doppler radar system (scatterometer). The processor package is designed to yield a specific product output of ice class utilizing radar measurements from Arctic sea ice. Although this processing system has not been developed to the point of actual data processing, the fundamental signal processing functions required for data reduction have been demonstrated.

The system implements two major levels of analysis: a) signal processing in which the data are reduced to corrected return magnitudes as a function of incident angle and b) classification analysis of this "scattering characteristic" to yield an ice class output.

The concept of a stand-alone scatterometer signal processor capable of real-time signal processing and analysis is significant not only in the development of the Arctic ice classification system but it also provides the means by which utilization of the radar scatterometer becomes more practical.

The inability to obtain timely data, in addition to the costly and time consuming computer analyses required for analysis, have hindered realization of the full potential of the radar scatterometer. The fully developed NOL signal

*Real time radar scatterometer signal processor and analog recorder*



*Laboratory set up for ground evaluation of the radar signal processor*

*Evaluating the radar signal processor*



analysis system will provide real-time processed output data at three levels. These include: a) a sign sensed doppler spectrum, b) corrected return magnitudes as a function of incident angle, and c) a read-out of ice class.

The first two types of output data will enhance scatterometer system utilization by providing the investigator with a) the assurance that valid measurements have been obtained, b) information regarding those portions of the data which are worthly of complete processing by available digital techniques, and c) data in the form of a sign-sensed or completely separated fore-aft doppler spectrum. These are significant factors because present digital processing time requirements are a minimum of eight times real-time. In addition, increased utility of this particular sensor by development of real-time analysis capability is of great importance in studies attempting to explain the scattering mechanism responsible for the radar return signal.

The Ryan system illuminates an area  $\pm 60^\circ$  along the flight line and  $\pm 1.5^\circ$  transverse to the flight line providing an analog output from which it is possible, after suitable operations, to extract information concerning the variation of the backscattered energy with incidence angle. The underlying physical principle governing the operation

of the Ryan scatterometer is the embedding of the variation of the backscattered energy with incidence angle in the frequency of the reflected signal. This phenomenon is a result of the doppler effect which establishes a sinusoidal relationship between the frequency shift about the center frequency transmitted by the radar and the angle of incidence. The signal reflected back to the radar antenna is a spectral distribution about the radar carrier frequency. The fore data, i.e. the return from positive incidence angles, is located in that portion of the backscattered spectrum greater than the radar carrier frequency. Those frequency components of the return signal below the carrier frequency are referred to as the aft data.

Since the Ryan scatterometer is a zero IF system, provision is made to separate the aft from the fore data (the aft data portion of the doppler spectrum will have been folded onto the fore data portion during heterodyning to baseband). This is provided for within the Ryan system by generation of two quadrature channels, one containing the sum of the fore and the aft signals and the other containing their difference.

Utilizing these quadrature channel inputs, five primary considerations arise in processing the data:

- separation of the fore and the aft return,
- sampling

those portions of the received doppler spectrum corresponding to the incidence angles of interest, c) generation of system timing to control spectral sampling and to allow for proper ground cell alignment, d) storage of the sample returns until a sample for each angle of interest for a particular ground cell has been acquired, and e) data correction for aircraft parameter variation.

Real-time scatterometer signal processing requirements dictate performance, concurrent with data acquisition, of the following functions: a) sign-sensing, b) data spectrum filtering, c) timing generation, d) sample storage, and e) data correction for aircraft parameter variation. The existing processor system designed and developed by the Remote Sensing Center, is structured to perform the first four of these functions. The system is composed of two module packages; these include: a) the Processor Module, responsible for conditioning the scatterometer output data and storage of the sampled return, and b) the Time Base Module, responsible for generation of all system timing.

The existing system is capable of simultaneous, real-time processing the radar return from a particular ground cell at five angles of incidence, with a cycle time of approximately 8 seconds.

The system includes a special purpose analog computer developed specifically to implement algorithms for classification of the radar returns according to sea ice type. The classification system uses a linear discriminator classification scheme and is programmable.

Laser Doppler Velocimeter Signal Processor -  
State-of-the-art remote sensing instrumentation for turbulent air velocity measurement includes recently developed Laser Doppler Velocimeter (LDV) systems which detect individual aerosol particle velocities via scattered laser light. The resulting data consists of randomly-timed samples of the velocity time history at the measurement point defined by a focused optical system. In single-component measurements of turbulent flow, the parameters of interest are mean velocity, normalized rms fluctuation (turbulence intensity), and power density spectrum.

The Remote Sensing Center is developing new theory and minicomputer algorithms for on-line computation of mean turbulence intensity and power density spectrum from randomly timed sampled data with low average data rates. The work is supported by the U.S. Air Force Arnold Engineering Development Center.

There are many applications for practical power spectrum analysis where it would be beneficial to deliberately use randomly timed data samples instead of periodic samples, because the Nyquist sampling criteria may be avoided. However, until very recently no practical estimation procedures utilizing randomly timed samples have been discussed in the literature. The LDV data analysis problem provides a concrete application where the sample times are random by nature, and it is necessary to search for new computational techniques. Such techniques have been located and are presently being modified for increased computational efficiency.

The results of the initial derivations, literature search, and feasibility experiments were presented at the Oklahoma State University "Workshop on Laser Doppler Anenometry", held June 11-13, 1973, Stillwater, Oklahoma. The improved results of later experiments have been presented at an invited lecture presentation at NASA Langley Research Center, August 27, 1973, and described in a paper to be presented at the 1973 National Telecommunications Conference, November, Atlanta, Georgia.

Lidar Polarimeter Signal Processor - The Lidar Polarimeter sensor being developed for the Coast Guard

includes a real-time signal processing and classification system for immediate identification of water conditions. The classification systems design is based upon the Arctic ice radar signal classifications system developed for NOL, however the Coast Guard system employs digital electronics. The system will be capable of continuous, real-time signal processing in support of an oil spill alert network.

## VI. SUMMARY

The 1972-73 programs emphasized the reorientation of the NASA Interdisciplinary Grant toward the demonstration of applications of remote sensing techniques. The professional staff was expanded to enable a rapid implementation of several new Applications projects developed in cooperation with state and federal agencies. The first year of this new program approach was extremely successful, due in part to the coincident development of an active interest in remote sensing by several agencies of the Texas state government. As a result, the program is scheduled for continued expansion during the coming year, and further involvement with personnel from the Office of the Governor of Texas is planned.

During this year the Center initiated new projects for the NASA Johnson Space Center, Naval Ordnance Laboratory, and the Coast Guard. These programs are in the area of remote sensing techniques and sensor system development, and, hence, assist in maintaining the balance in the Center between the Applications and Supporting Technology areas.

The Center has agreed to provide technical and administrative support to the Johnson Space Center in the conduct of an Active Microwave Workshop to be held in 1974.

The workshop project will document the status of active microwave sensing of earth resources and the environment. The Center also anticipates participation in the NASA Joint Soil Moisture Experiment scheduled for the Spring 1974. This project will combine the expertise of several investigators working in this field in an attempt to establish the potential of microwave sensors for remote soil moisture monitoring.

## VII. PUBLICATIONS

### A. Technical Reports

The following is a complete list of Technical Reports published by the Remote Sensing Center:

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- RSC-01 Radar Scatterometer Data Analysis  
NASA/MSC Mission 73, Site 130  
J. W. Rouse, Jr. - May 1969
  - RSC-02 Infrared Detection Of Concrete Deterioration  
R. H. Arnold, H. L. Furr, and J. W. Rouse, Jr.  
July 1969
  - RSC-03 Passive Microwave Sensing Of The Earth's Environment: A Bibliography With Abstracts  
J. A. Richerson - September 1969
  - RSC-04 Discussion Of The Least Squares Technique And Development Of A Curve Fitting Subroutine  
T. A. Eppes - September 1969
  - RSC-05 Infrared Detectors: Special Interest Bibliography With Abstracts  
R. H. Arnold - September 1969
  - RSC-06 Remote Sensing Of Crop Water Deficits And Its Potential Applications  
W. P. David - September 1969
  - RSC-07 Remote Sensing Of Crop Water Deficits: Bibliography With Abstracts  
W. P. David - September 1969
  - RSC-08 Remote Sensing In Agriculture: Agronomic Sciences A Selected Bibliography With Abstracts  
R. H. Griffin II - September 1969
  - RSC-09 Radar Scatterometer Data Analysis: Sea State NASA/MSC Mission 20 and Mission 34  
R. W. Newton - May 1970
  - RSC-10 Discussion Of A Model Of The Apparent Temperature Of Natural Surfaces In The Microwave Range  
J. A. Richerson - May 1970

- RSC-11 The Size-Filtering Effect Inherent In The Slope-Facet Model Of Radar Backscatter From The Sea  
J. W. Rouse, Jr. - August 1970
- RSC-12 Wavelength Dependence Of Backscatter From Rough Surfaces  
J. W. Rouse, Jr. - August 1970
- RSC-13 On Air Temperature Fluctuations Immediately Above A Glacier Surface  
Aylmer H. Thompson and Paul E. Carrara - August 1970
- RSC-14 Analysis And Evaluation Of A Forward-Viewing Scanning Radar Scatterometer System  
R. H. Arnold - August 1970
- RSC-15 Aerial 8-14 Micron Imagery Applied To Mapping Thermal Effect Mixing Boundaries  
Norman Gray Foster - August 1970
- RSC-16 Remote Sensing Techniques Used In Determining Changes In Coastlines  
John B. Herbich and Zelton L. Hales
- RSC-17 Procedures In Pattern Classification  
J. A. Schell - September 1970
- RSC-18 Development Of An Airborne Remote-Sensor Survey Of Tree Diseases In Texas  
E. P. Van Arsdel - September 1970
- RSC-19 Determination Of The Correlation Between The Initial Respiratory Heat Output Of Imbibed Seeds And Their Subsequent Germination And Vigor  
John D. Goeschl - September 1970
- RSC-20 Radar Studies Of Arctic Ice  
J. W. Rouse, Jr. and J. A. Schell - October 1970
- RSC-21 Remote Detection Of Water Depletion In Cropped Fields  
A. R. Aston and C. H. M. van Bavel - June 1971
- RSC-22 Survey of Remote Sensing Applications to Hydrology With A Selected Bibliography  
Sidney W. Sers - October 1971
- RSC-23 Laboratory Measurement of the Complex Dielectric Constant of Soils  
M. L. Wiebe - June 1971

- RSC-24      Remote Detection and Analysis of Vegetative Cover on Texas Rangelands: Woody Plants  
R. H. Haas and R. L. Watson - March 1971
- RSC-25      Experimental Microwave Measurements of Controlled Surfaces  
B. R. Jean, J. A. Richerson, and J. W. Rouse, Jr.  
May 1971
- RSC-26      A Spatial Frequency Analysis of the Geologic Information Content of SLAR Images  
T. A. Eppes and J. W. Rouse, Jr. - May 1971
- RSC-27      An Experimental Evaluation of a Theoretical Model of the Microwave Emission of a Natural Surface  
J. A. Richerson - August 1971
- RSC-28      The Use of Spatial Frequency Analysis Techniques in the Investigation of the Geologic Information Content of Radar Images  
T. A. Eppes - August 1971
- RSC-29      On the Use of Radar Backscatter Measurements to Classify Sea State in the Gulf of Mexico  
R. W. Newton - August 1971
- RSC-30      Selected Applications of Microwave Radiometric Techniques  
B. R. Jean - August 1971
- RSC-31      Analysis of Approximated Multispectral Data from Earth Resource Satellites  
D. White - December 1971
- RSC-32      Microwave Radiometer Measurements of Soil Moisture  
B. R. Jean, C. L. Kroll, J. A. Richerson, J. W. Rouse, Jr., T. G. Sibley, and M. L. Wiebe  
October - 1972
- RSC-33      Quantitative Evaluation of Water Quality in the Coastal Zone by Remote Sensing  
W. P. James - September 1971
- RSC-34      A Practical Method of Determining Water Current Velocities and Diffusion Coefficients in Coastal Waters by Remote Sensing Techniques  
W. P. James - October 1971

- RSC-35      Analysis Of Simulated Multispectral Data From  
Earth Resources Satellites  
D. A. White, J. W. Rouse, Jr., and J. A. Schell  
August - 1971
- RSC-36      A Comparison Of Two Approaches For Category  
Identification And Classification Analysis  
From An Agricultural Scene  
J. A. Schell - 1972
- RSC-37      On the Performance of Infrared Sensors in  
Earth Observations  
Luther F. Johnson    August 1972
- RSC-38      Application of Remote Sensing to Water Quality  
Management in the Coastal Area  
Dr. Wesley P. James
- RSC-39      Use of Large Scale Aerial Photography in Obtaining  
Vegetation Information for Urban Planning  
R. H. Haas and M. C. McCaskill  
August 1972
- RSC-40      Lidar Polarimeter: Experimenter Feasibility  
Study  
G. J. Wilhelmi, W. T. Mayo, Jr., and J. W. Rouse, Jr.  
September 1972
- RSC-41      On a Systems Approach to Earth Observations  
J. W. Rouse, Jr. and J. A. Schell - December 1972
- RSC-42      Water Quality Parameter Measurement Using  
Spectral Signatures  
Paul Edward White    August 1973
- RSC-43      Remote Monitoring of Soil Moisture using  
Airborne Microwave Radiometers  
Charles Lindsey Kroll    August 1973
- RSC-44      Microwave Emission and Scattering From Vegetated  
Terrain  
Terrell Gene Sibley - August 1973
- RSC-45      An Investigation of the Depolarization of Back-  
scattered Electromagnetic Waves Using a Lidar  
Polarimeter  
Gary Joe Wilhelmi - August, 1973
- RSC-46      The Development of a Signal Processing Network  
for a Real-Time Arctic Sea Ice Classification  
System  
William Douglas Nordhaus - August, 1973

- RSC-47      Remote Measurement of Turbidity and Chlorophyll  
                to Aerial Photography  
                Martin Schwebel - October, 1973
- RSC-48      Real-Time Processing of Remote Sensor Data As  
                Applied to Arctic Ice Classification  
                James Permenter - December - 1973
- RSC-49      A Digital Color CRI Image and Graphics Display  
                for Data Analysis  
                Francis Joseph Bruns - December, 1973
- RSC-50      Remote Detection of Deer Habitat Factors  
                Ken R. Moore & R. H. Haas, November, 1973

### B. Technical Memorandums

The following is a complete list of Technical Memorandums published by the Remote Sensing Center:

- RSC-01 Spatial Adjustment Discrepancies In Scatterometer Data From Mission 73  
T. A. Eppes - February 1969
- RSC-02 Comments On The Gulf Of Mexico And Its Weather  
R. W. Newton - August 1969
- RSC-03 Documentation Of Five Data Analysis Subroutines  
T. A. Eppes and J. C. McFarland III - February 1970
- RSC-04 Comments On Microwave Sensing Of Soil Moisture  
B. Randall Jean - April 1970
- RSC-05 Remote Sensing - Geophysical Application  
J. W. Rouse, Jr. - May 1970
- RSC-06 Comments On Microwave Radiometry As A Remote Sensor For The Geosciences  
B. Randall Jean - May 1970
- RSC-07 Spatial Frequency Analysis Using Optical Fourier Transforms  
T. A. Eppes - May 1970
- RSC-08 Development Of A Computer Programming Package For Digital Spatial Frequency Analysis Of Images  
T. A. Eppes - May 1970
- RSC-09 Remote Detection Of Water Depletion In Cropped Fields  
A. R. Aston - September 1970
- RSC-10 Determination Of An Operational Technique For Classification Of Sea States In The Gulf Of Mexico  
R. W. Newton - September 1970
- RSC-11 Determination Of The Feasibility Of Using Infrared Sensing For Aerial Surveys Of White-Tailed Deer  
J. W. Rouse, Jr., E. D. Ables, N. F. Forrest, and P. O. Reardon - May 1970

- RSC-12 Parameters Affecting The Detection Of Wildlife  
With An Aircraft-Mounted Infrared Scanner  
G. R. Harker - May 1970
- RSC-13 Radar Image Simulation Using Controlled Surfaces  
T. A. Eppes - September 1970
- RSC-14 Delineation Of Flood Plains Using Automatically  
Processed Multispectral Data  
G. R. Harker - May 1970
- RSC-15 The Size-Filtering Effect Inherent In The Slope-  
Facet Model Of Radar Backscatter From The Sea  
J. W. Rouse, Jr. - August 1970
- RSC-16 Comments On A Frequency Autocorrelation Function  
Richard H. Arnold - September 1970
- RSC-17 Optical Mechanical Scanner As Compared To  
Photographic Process In Multispectral Data  
Collection  
George R. Harker - August 1970
- RSC-18 Simulation Of ERTS-A Multispectral Scanner Data  
David White - September 1970
- RSC-19 Scatterometer Data Reduction  
R. W. Newton - September 1970
- RSC-20 Delineation Of Flood Plains Using Automatically  
Processed Multispectral Data - Ground-Truth  
Study  
George R. Harker - September 1970
- RSC-21 Comparison Of Peake's Microwave Emission Model  
To Experimental Measurements  
Jerry A. Richerson - April 1971
- RSC-22 Various Techniques of Dielectric Constant  
Measurement As Applied To The Relative Dielectric  
Constant of Sand As A Function Of Moisture Content  
Michael L. Wiebe - May 1971
- RSC-23 Development Of The Reflection Coefficient Of A  
Layered Dielectric  
Jerry A. Richerson - May 1971

- RSC-24      Ground Truth Report: NASA/GSFC CV-990 Mission  
At Test Site 32, Weslaco, Texas  
Buford Randall Jean - March 1-2, 1971
- RSC-25      Optical Correlator Systems  
T. A. Eppes - July 1971
- RSC-26      Environmental Study: Houston Ship Channel And  
Galveston Bay  
Dr. W. P. James - September 1971
- RSC-27      Ice Type Identification Processor Studies  
Gary Joe Wilhelm - March 1971
- RSC-28      Experimental Measurements Of 2.25 cm Backscatter  
From Sea Surfaces  
R. W. Newton and J. W. Rouse, Jr. - September 1971
- RSC-29      Viewing Angle Effects In Radar Images  
T. A. Eppes and J. W. Rouse, Jr. - September 1971
- RSC-30      Microwave Characteristics of Soil Surfaces  
B. R. Jean, J. A. Richerson, J. W. Rouse, Jr.,  
and M. L. Wiebe - September 1971
- RSC-31      Analysis Of Simulated Multispectral Data From  
Earth Resource Satellites  
J. A. Schell, P. E. White, and J. W. Rouse, Jr. -  
September 1971
- RSC-32      Estimation Of Surface Roughness Characteristics  
J. A. Richerson - September 1971
- RSC-33      Development Of The Reflection Coefficient Of A  
Layered Dielectric  
J. A. Richerson - September 1971
- RSC-34      A New Philosophy Of Microwave Remote Sensing  
J. W. Rouse, Jr. - October 1971
- RSC-35      Effects Of Sampling A Scatterometer Return Signal  
For Computation Of A Discrete Fourier Transform  
T. G. Sibley - December 1971
- RSC-36      Reevaluation Of The Correlation Of Measured  
Apparent Temperature To Soil Moisture Content  
T. G. Sibley - December 1971

- RSC-37      Characterization of Arctic Ice Using Radar Backscatter  
                 J. W. Rouse, Jr. - January 1972
- RSC-38      A Laser Air Pollution Monitor  
                 G. J. Wilhelmi - January 1972
- RSC-39      Electronic Analog Computer Design Considerations  
                 James A. Permenter - January 1972
- RSC-40      Analysis of Processing Techniques For The Reduction of Data Produced by a Radar Scatterometer System  
                 W. D. Nordhaus - January 1972
- RSC-41      The Effect of the Subsurface on the Depolarization or Rough Surface Backscatter  
                 J. W. Rouse, Jr. - September 1971
- RSC-42      Two Dimensional Fourier Transform Program  
                 Gary J. Wilhelmi - April 1972
- RSC-43      Summary of Fast Fourier Transform  
                 Gary J. Wilhelmi - April 1972
- RSC-44      A Discussion of the Complexities of Laser Doppler Velocimeter Systems for Measurements of Turbulence  
                 W. T. Mayo, Jr. - May 1972
- RSC-45      Complex Dielectric Constant Measurements for Selected Soil Types  
                 C. L. Kroll and T. G. Sibley - May 1972
- RSC-46      Weslaco Ground Truth Survey in Support of NASA/GSFC CV-990 Aircraft  
                 C. L. Kroll - June 1972
- RSC-47      Radar Scatterometer Analysis Program Documentation: SCATPGM, Version 1.0, May 1972  
                 J. A. Schell - October 1972
- RSC-48      Ground Observations for Water Quality Study  
                 Paul E. White - July 1972
- RSC-49      The Design and Operation of a 12/2000 Volt Programmable Power Supply  
                 Thomas C. Sheives - June 1972

- RSC- 50 "Background Study into Remote Sensing of Water Quality"  
G. J. Wilhelmi -
- RSC- 51 Discussion of a Simplified Procedure for Measuring Dielectric Constant of Soil as a Function of Moisture Content  
Terrell G. Sibley - July 1972
- RSC- 52 On the Effect of Moisture Variations on Radar Backscatter from Rough Soil Surfaces  
John W. Rouse, Jr. - July 1972
- RSC- 53 The New Era of Environmental Monitoring  
J. W. Rouse, Jr. - July 1972
- RSC- 54 ERTS-A Multispectral Sensor Data Handling  
Roger Sorrells - July 1972
- RSC- 55 "A Low Cost Variable Intensity Light Table for Laboratory Use"  
M. C. McCaskill and R. H. Haas
- RSC- 56 "Spectral Reflectance Measurements of A Virus Host Model (St. Augustine Decline)"  
Dr. R. W. Toler  
1972
- RSC- 57 "Remote Water Quality Measurements With A Lidar Polarimeter"  
Gary Wilhelmi - September 1972
- RSC- 58 "A Dual Polarization Laser Backscatter System for Water Quality Studies"  
W. T. Mayo, Jr., G. J. Wilhelmi, J. W. Rouse, Jr.  
September - 1972
- RSC- 59 "Description of A Computer Package to Classify Multi-Spectral Scanner Data"  
Thomas S. Parker - September 1972
- RSC- 60 "A New Method For Determining the Aerodynamic Size of Particulate Pollutants"  
Thomas C. Sheives - October 1972
- RSC- 61 "Predications of Apparent Temperatures of Several Agricultural Test Sites"  
October 1972  
Terrell Sibley

- RSC-62 "Detection of Oil on Water with a Lidar Polarimeter: Preliminary Feasibility Measurements  
W. T. Mayo, Jr. and G. J. Wilhelm  
October 1972
- RSC-63 "Great Plains Corridor Rangeland Test Sites"  
D. W. Deering and R. H. Haas - September 1972
- RSC-64 "Uses of Remote Sensing in Agriculture: A Survey of Potential Applications"  
K. R. Moore and R. H. Haas - October 1972
- RSC-65 "Oceanographic Remote Sensing at Texas A&M University - G. L. Huebner, Jr. - October 1972
- RSC-66 "A Color CRT Display For Remote Sensing Data Analysis" - Frank J. Bruns - October 1972
- RSC-67 "Airphoto Analysis of Ocean Outfall Dispersion  
Wesley P. James - June 1972
- RSC-68 "The Depolarization of Linearly Polarized Laser Light Backscattered From Turbid Water" - Thomas C. Sheives - March 1973
- RSC-69 "On the Measuring of Soil Moisture By Microwave Radiometric Techniques" - C. L. Kroll, T. G. Sibley, and J. W. Rouse, Jr. - April, 1973.
- RSC-70 "Image Densitizer for Remote Sensing Data Analysis"  
Thomas S. Parker - April 1973
- RSC-71 "Ground Data Collection at the ERTS-1 Great Plains Corridor Test Sites" - D. W. Deering - April 1973
- RSC-72 "An Introduction to the Estimation of Power Spectra Single Particle LDV Data" - W. T. Mayo, Jr., S. Riter, M. T. Shay - May 1973
- RSC-73 "On Radio Science Techniques for Remote Sensing"-  
John W. Rouse, Jr. - June 1973
- RSC-74 "A Color CRT Image Display System" - F. J. Bruns, V. T. Rhyne, & J. A. Schell
- RSC-75 "Report on Lidar Polarimeter Measurements Conducted on Brazos River at Waco, Texas" -  
Thomas C. Sheives - June 23-24, '73

- RSC- 76 "Multi-Data-Set-Plot Program" - Homayoun Malek,  
August 1973
- RSC- 77 "Spectral Reflectance Meas. of Maize Dwarf Mosaic  
Virus Infected Sorghum" - Toler & Haas - 1973
- RSC- 78 "An Initial Design Analysis of a Synchronous  
Demodulator (Lock-In Amplifier) Preamplifier Sec-  
tion for a Two Wavelength Lidar Polarimeter"  
William Hulse - October, 1973
- RSC- 79 "Implementation of an Algorithm for Abstraction  
of Linear 'Decision Function" - Homayoun Malek -  
September, 1973
- RSC- 80 "Applicatons of Remote Sensing in Civil Engin-  
eering" - Wesley P. James & David J. Barr -  
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- RSC- 81 "The Delineation of Flood Plains Using Automatic-  
ally Processed Multispectral Date" - George R.  
Harker - September, 1973
- RSC- 82 "The Development of New Digital Data Processing  
Techniques for Turbulence Measurements With a  
Laser Velocimeter: - Mayo, Shay, & Riter -  
October, 1973
- RSC- 83 "Lidar Polarimeter Measurements of Water Pollution"  
Dr. John W. Rouse, Jr. - October 1, 1973
- RSC- 84 "Soil Skin Depth Determination" S. L. Lee, October.  
1973
- RSC- 85 "Real Time Signal Processing" J. W. Rouse, Jr.  
November, 1973

MONITORING VEGETATION SYSTEMS IN THE  
GREAT PLAINS WITH ERTS

J. W. Rouse, Jr., R. H. Haas, J. A. Schell, and D. W. Deering

*Abstract*

The Great Plains of the central United States produces over forty percent of the nation's beef and much of the country's grain. The beef industry in this region is a \$23 billion operation, which is extremely vulnerable to adverse seasonal or climatic conditions. The stability of the beef and agricultural products industry in the Great Plains is contingent upon decisions made by the 400,000 farm and ranch owners in this region. These private operators need timely information on regional range forage conditions and crop production levels upon which to base their management decisions. This paper reports on an ERTS-1 study of rangelands in the Great Plains that has established the potential for using ERTS-type data to provide quantitative regional vegetative condition information required to support these agricultural operations.

The Great Plains Corridor rangeland project being conducted at Texas A&M University utilizes natural vegetation systems as phenological indicators of seasonal development and climatic effects upon regional growth conditions. The basic task is that of monitoring the vernal advancement and retrogradation of vegetation (green wave effect) throughout the uniform Mixed Prairie Grassland Association extending from south Texas into Canada. The objective of the work is to determine the feasibility of using ERTS-type data to map regional vegetation conditions throughout the growing season for the Great Plains.

The study employs a network of ten test sites in six states extending from south Texas into North Dakota. Ground observations recorded every eighteen days at each site include green biomass, moisture content of vegetation, weather information, etc. ERTS-1 MSS data have been acquired for all sites for four full seasons.

The ERTS-1 MSS data were computer processed for selected areas of each site. Spectral reflectance data were analyzed for each available date for each site. The measurements were corrected for seasonal sun angle differences to

permit temporal comparisons. Radiance values recorded in ERTS-1 spectral bands 5 and 7 were used to compute a Band Ratio Parameter which is shown to be correlated with above-ground green biomass and vegetation moisture content.

This research has established a method for obtaining a quantitative measurement of vegetation conditions over broad regions using ERTS-1 MSS data. It is anticipated that this capability will be further developed to provide regional rangeland vegetation condition and growing condition information needed in rangeland management and agri-business activities in the Great Plains.

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Presented at the ERTS Symposium, December 10-13, 1973,  
Washington, D.C.

Technical Report RSC-50  
REMOTE DETECTION OF DEER HABITAT FACTORS

K. R. Moore and R. H. Haas

*Abstract*

Color-IR aerial photography and ground observations were acquired at two sampling dates from three grazing pastures and two soil types at the Sonora Range Station. Vegetation characteristics influencing deer habitat components (food and cover) were measured from ground and air photo surveys. Aerial photography provided information necessary for evaluating deer habitat by delineating and classifying food-cover types on three study pastures. Reliability of the habitat classification scheme was determined by comparing the location and extent of favorable types to available deer density counts.

Ground observations provided fundamental data for assessing the accuracy of air photo measurements. The point-centered quarter (PCQ), plotless technique was employed to measure composition, density, and canopy cover of woody vegetation from ground and air photo surveys. Air photo quadrat methods were used to estimate density and canopy cover. An air photo dot grid method was also employed to determine canopy cover.

Woody plant composition measured by ground and air photo survey compared well for major species. Density estimated from ground and air photo PCQ data were consistently higher than air photo quadrat counts. Canopy cover was poorly estimated from ground observations but was accurately measured by air photo methods. The air photo quadrat and dot grid techniques produced very similar canopy cover percentages. Air photo measurements were obtained with relative ease and in a small fraction of the time required for ground measurements. Qualitative estimates of herbage yield and standing green biomass compared well with quantitative ground measurements.

Important vegetation characteristics of deer habitat were used to classify food-cover types. Food-cover type mapping and characterization were possible from medium to large scale color-IR aerial photography. Suitable classes of food-cover types developed for this investigation agreed well with available deer density data for the test pastures.

## Technical Report RSC-42

WATER QUALITY PARAMETER MEASUREMENT  
USING SPECTRAL SIGNATURES

P. E. White

*Abstract*

Increased concern about water quality and the lack of fast, inexpensive methods of measuring water quality parameters over large areas have prompted interest in remote sensing techniques. Previous studies indicate that some water quality parameters influence remotely sensed spectral signatures, but currently there is no method of measuring water quality parameters from spectral signatures.

This study applies regression analysis to the problem of measuring water quality parameters from remote sensing spectral signature data. It presents the equations necessary to perform regression analysis and describes methods of testing the strength and reliability of a regression. It also presents an efficient algorithm for selecting an optimal subset of the independent variables available for a regression.

To illustrate the regression techniques, they are applied to a particular set of data from the Houston Ship Channel. Unfortunately, deficiencies in the quality and quantity of the data that were available prevent definite conclusions to be drawn from the analysis.

Results of the study show that regression analysis is applicable to the problem of measuring water quality parameters from remote sensing spectral signatures, but that the utility of the method needs further testing on much larger sets of data.

Recommendations resulting from this study are that regression analysis techniques be applied to data from ERTS-1, and that new water quality parameters based on the reflective characteristics of water be defined for improved correlation with remote sensing data.

## Technical Report RSC-47

REMOTE MEASUREMENT OF TURBIDITY AND CHLOROPHYLL  
THROUGH AERIAL PHOTOGRAPHY

M. D. Schwebel

*Abstract*

Studies were conducted utilizing six different film and filter combinations to quantitatively detect chlorophyll and turbidity in six farm ponds. The low range of turbidity from 0-35 JTU correlated well with the density readings from the green band of normal color film and the high range above 35 JTU was found to correlate with density readings in the red band of color infrared film. The effect of many of the significant variables can be reduced by using standardized procedures in taking the photography.

Attempts to detect chlorophyll were masked by the turbidity. The ponds which were highly turbid also had high chlorophyll concentrations; whereas, the ponds with low turbidity also had low chlorophyll concentrations. This prevented a directed correlation for this parameter.

Several suggested approaches are cited for possible future investigations.

Technical Memorandum RSC-80

APPLICATIONS OF REMOTE SENSING IN CIVIL ENGINEERING

David J. Barr, Wesley P. James

*Abstract*

With the development of new hardware capable of sensing emitted and reflected energy throughout the electromagnetic spectrum and with new and improved recording devices, many fresh applications of remote sensing to civil engineering endeavors are practical. Such practical applications are briefly described and documented. Remote sensor use in monitoring water quality is presented in more detail as a case study.

## Technical Memorandum RSC-81

THE DELINEATION OF FLOOD PLAINS USING  
AUTOMATICALLY PROCESSED MULTISPECTRAL DATA

George R. Harker

*Abstract*

Remote sensing may be able to play a significant role in the development of a successful program to delineate flood plains and thereby aid in the implementation of the Federal Flood Policy involving the control of flood plains. An experiment was undertaken to evaluate a technique using multispectral data that may permit the rapid and accurate delineation of flood plain areas, minimizing extensive field work or numerous hydrologic calculations. A test site for this experiment was selected just north of College Station, Texas along a twenty-five mile section of the Navasota River. This section existed in a relatively natural state, suggesting that natural parameters associated with the flood plain may not have been measurably disturbed. Aerial infrared photographs of the test site were obtained, converted to a simulation of multispectral scanner data, processed using automatic classification techniques previously developed in the remote sensing field, and compared with the classified data of the known test site flood plain. The flood plain boundary delineated by the simulated multispectral data correlated well with the boundary developed by the Corps of Engineers corresponding to a discharge of 50,000 CRS. These results were analyzed and related to the flood hazard problem currently existing in the United States.

## Technical Memorandum RSC-77

SPECTRAL REFLECTANCE MEASUREMENTS OF MAIZE DWARF MOSAIC  
VIRUS INFECTED SORGHUM

Dr. R. W. Toler

*Abstract*

Grain Sorghum (*Sorghum vulgare* pers.) a susceptible host for Maize Dwarf Mosaic Virus was used as the type host to study spectral reflectance properties in order to differentiate between healthy and MDMV infected plants by remote sensing techniques. This host was selected because of it's economic importance in Texas and the Southwest. In addition this virus-host combination has the following characteristics 1) sorghum gives a typical mosaic reaction plus a red-leaf stage that produces necrotic areas, 2) it is a hybrid summer annual, 3) well adapted to the test site area, 4) genetically stable, 5) susceptible to mechanical transmission of the virus, and 6) typical of cultivated row crops. Laboratory measurements of spectral reflectance using a Cary 14 spectrophotometer were made on plants grown and virus inoculated in the greenhouse. Spectral measurements were made (350 nm to 900 nm) on healthy sorghum and plants infected for 3 days and plants infected 7 days or more. Analysis of the data indicated four possible regions which can be used for spectral differentiation between healthy and MDMV diseased sorghum. These regions are centered on 450 nm, 525 nm, 650 nm and 800 nm. Maize Dwarf Mosaic Virus was detected in sorghum and severity estimates were made using aerial photographic techniques. Ground truth sites were established in 1972 and the 1973 growing seasons and photographed from a remote platform. Photographic imagery, using Ektachrome Aero 2443 that was processed to positive transparencies, was obtained from a Zeiss RMK A 15/23 (9" x 9") camera equipped with a Zeiss D (0525 nm) cutoff filter mounted in a modified De Haviland Beaver Aircraft. Density points and density ranges were established using a stereoscopic viewer. MDMV diseased sorghum

was detected and disease severity established after peak symptom development. Disease severity ratings from ground truth and color IR transparencies compared favorably. This method provides rapid assessment and a permanent record of the disease ratings.

REMOTE SENSING TECHNIQUES FOR DETECTING VIRUSES  
AND THEIR DISSEMINATION

Robert W. Toler

*Abstract*

Bawden in 1933 first visualized infrared photograph techniques for detection of virus symptoms. In our calculations, St. Augustine Decline (SAD) caused by the SAD strain of *Panicum Mosaic Virus* was selected as a virus-host model to determine multispectral tone signatures of healthy and diseased grass. Techniques for data acquisition include 1) measurements of spectral reflectance of samples in the laboratory using the Cary 14 RI spectrophotometer, 2) measurements in the field of spectral reflectance of control plots with spectroradiometers, 3) analysis of measurements of polarization in the laboratory using a Cary-14 RI spectrogoniophotometer, 4) temperature measurements of control plots to obtain heat emission with radiometers and 5) photography of field plots using multiband photographic sensors with various film/filter/polarization combinations. Data analysis of imagery includes color density contouring and density slicing technique employing the multiband TV display unit to ratio densities of different regions of the visible spectrum to enhance density discrimination between healthy and virus infected plants. Density signature analysis with color IR is accomplished using microdensitometers and digital computers. Computer-drawn histograms supply counts of density points per density range allowing calculations of percentages of disease ratings as a function of the total area scanned.

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Presented at the Second International Congress of Plant Pathology, September 5-12, 1973, University of Minnesota.

Technical Report RSC-43  
REMOTE MONITORING OF SOIL MOISTURE USING  
AIRBORNE MICROWAVE RADIOMETERS

C. L. Kroll

*Abstract*

Several remote sensors have been proposed as potentially applicable for monitoring soil moisture. Microwave sensors appear to have an advantage over shorter wavelength sensors because of their deeper penetration into the soil and their relative immunity to atmospheric effects. The capability of airborne microwave radiometers to monitor soil moisture was investigated.

In this report the current status of microwave radiometry is provided. The fundamentals of the microwave radiometer are reviewed with particular reference to airborne operations, and the interpretative procedures normally used for the modeling of the apparent temperature are presented.

Airborne microwave radiometer measurements were made over selected flight lines in Chickasha, Oklahoma and Weslaco, Texas. Extensive ground measurements of soil moisture were made in support of the aircraft mission over the two locations. In addition, laboratory determination of the complex permittivities of soil samples taken from the flight lines were made with varying moisture contents.

The data were analyzed to determine the degree of correlation between measured apparent temperatures and soil moisture content. The Chickasha fields were fairly dry (<20% moisture content) and no correlation of apparent temperature with soil moisture existed for the Chickasha data. A heavy rain preceding the Weslaco flight invalidated the ground soil moisture measurements. However, an assumed value of the soil moisture content of the Weslaco fields was derived from known moisture retention curves for the soil type. The combined results of the Chickasha and Weslaco experiments using the derived soil moisture values

yielded a high degree of correlation of apparent temperature and soil moisture. Regression analysis indicated a  $-2.15^{\circ}\text{C}/\text{percent}$  moisture variation in apparent temperature for the 1.42 GHz radiometer, vertical polarization, for bare or nearly bare fields, which compares favorably with the results reported by Jean [10]. The center cell of the 19.4 GHz, horizontal polarization, had an average variation in apparent temperature of  $-1.5^{\circ}\text{C}/\text{percent}$  moisture when observing vegetated fields.

## Technical Report RSC-44

MICROWAVE EMISSION AND SCATTERING FROM  
VEGETATED TERRAIN

T. G. Sibley

*Abstract*

In this report, models are developed for the apparent temperature and backscatter coefficient of vegetated terrain to illustrate the effects of vegetation on the sensitivity of these parameters to variations of soil moisture. Three types of terrain are simulated for both the passive and the active case: a uniform canopy over a smooth surface, plant rows on a smooth surface, and plant rows on a rough surface. In each case the canopy is defined by its overall dimensions and by its electric permittivity, which is determined from the Weiner model for dielectric mixture. Emission and scattering from both the soil and the canopy are considered, but atmospheric effects are neglected.

The expression for the apparent temperature of vegetated terrain includes terms for the apparent temperature of the bare soil and of the canopy. The bare soil term is modified by an exponential term to account for attenuation of radiation from the soil by the canopy. The term which represents radiation by the canopy assumes that the canopy is a homogeneous layer. The expression for the apparent temperature of row crops is the average of the apparent temperatures of covered or shadowed soil and visible bare soil. A rough surface is represented by a surface roughness factor and a coefficient of effective area of specular refraction.

The expression for the backscatter coefficient of vegetated terrain is similar to the expression for apparent temperature. The term for backscatter from smooth, bare soil is determined by the physical optics method. The term for backscatter from the canopy is a modified form of a model for scattering from long, thin dielectric cylinders.

Calculated data indicate that the sensitivity of the apparent temperature and backscatter coefficient to variations of soil moisture, decreases as the amount of vegetation increases. It is shown that the same effect results from increasing signal frequency or angle of incidence.

Several sets of equivalent vegetation states, defined as different combinations of parameters which yield equivalent data, are tabulated. It is shown that in many cases the height-density product of a uniform canopy may be used to identify equivalent states.

Technical Report RSC-46

THE DEVELOPMENT OF A SIGNAL PROCESSING NETWORK FOR  
A REAL-TIME ARCTIC SEA ICE CLASSIFICATION SYSTEM

W. D. Nordhaus

*Abstract*

*The development of an electronic signal processing network for a real-time Arctic sea ice classification system is described in this report. As designed, the processor is able to accept the recorded analog output from a Ryan Redop radar scatterometer and reduce this information to a series of voltage levels proportional to the magnitude of the radar backscatter at desired angles of incidence.*

*The characteristics of the radar scatterometer and the results of several studies of the radar return from Arctic sea ice are presented. A mathematical analysis is given to establish the properties of the data obtained from the Ryan Redop scatterometer and to determine those operations which must be performed to successfully reduce these data. Four processing approaches capable of manipulating the radar data in the required manner and the signal reduction technique implemented in the processor system are discussed in detail. The circuit design employed in the processor and the results of the system performance testing are described. Finally, recommendations for possible modification of the system and areas requiring additional investigation are presented.*

Technical Report RSC-48

REAL-TIME PROCESSING OF REMOTE SENSOR DATA AS APPLIED  
TO ARCTIC ICE CLASSIFICATION

J. A. Permenter

*Abstract*

The development of a special purpose electronic analog computer to be used as a sub-unit in a real-time Arctic ice classification system is described in this report. The unit is designed to accept radar data which has been reduced to a series of voltage levels proportional to the magnitude of the radar backscatter at desired angles of incidence. Utilizing these data, the system performs a classification analysis to categorize the data into major ice groupings. The unit is programmable and can be used to investigate any of several classification techniques.

The radar scatterometer, in conjunction with a radar signal processing network developed in a parallel study, is discussed. The analog circuit design is presented and a classification algorithm is developed. In addition, a description of the preliminary system test utilizing the developed algorithm and digitally processed data from a NASA Arctic mission is presented, along with results. Finally, recommendations for system improvement and implications of this study are given.

## Technical Report RSC-49

A DIGITAL COLOR CRT IMAGE AND GRAPHICS  
DISPLAY FOR DATA ANALYSIS

F. J. Bruns

*Abstract*

The increasing use of computers for processing and enhancement of imagery has created a need for a flexible, high-speed, interactive interface between the computer and the human investigator. In the past, this interface has taken the form of a monochromatic CRT display. The use of the monochromatic display, however, has been limited by the inability of the human eye to discriminate between intensity levels of gray. This has led to the use of color displays to display both true color images and color enhanced black and white images.

This thesis describes the design and development of a totally digital color image display system utilizing a standard color television receiver as the display device. The use of a commercial television receiver provides a source of a low cost display terminal and allows simple expansion for multiterminal applications.

In addition to the simple display of computer generated or enhanced images, this display system has provisions for real-time interaction between both the computer and the displayed data and the operator and the displayed data. The computer interaction is enabled by a set of command instructions provided to the computer. Through these instructions, the computer can modify selected portions of the displayed data, as well as extract numeric data directly from the screen. The operator interacts with the display system through a control panel. Using the controls available, the operator can select the color coding of the image, expand selected portions of the screen or extract data from the screen and display the data in a numeric readout. The display system and the operator interface provisions are completely independent

of the computer; once the data have been transferred from the computer, the display is a stand-alone unit.

Recommendations are made regarding the future utilization of this display system and the development of possible additional features. Also discussed are selected software routines which could be generated to realize the full potential of the computer interaction instruction set.

## Technical Report RSC-45

AN INVESTIGATION OF THE DEPOLARIZATION OF  
BACKSCATTERED ELECTROMAGNETIC WAVES  
USING A LIDAR POLARIMETER

G. J. Wilhelm

*Abstract*

In this study, the Kirchhoff approach following Leader [1] and Rouse [2] has been extended to encompass backscatter contributions from both the surface and subsurface. This extension included both polarized and depolarized components. In order to investigate the validity of the assumptions concerning the physical phenomenon utilized in the theoretical development, a series of dual polarization laser backscatter measurements of rough surfaces exhibiting a volume scattering process were performed. The experiment utilized both smooth turbid water and cast dielectric samples. The turbid solutions investigated were composed of a high concentration of scatterers and absorbing material to control the amount of volume scatter. The dielectric samples were pigmented to vary the amount of volume scatter from a negligible amount to a level where the surface scatter was negligible. Also, the surface roughness of the samples was varied from a very rough to a moderately rough surface. Using these targets, polarized and depolarized backscatter measurements were recorded using both horizontal and vertical transmit polarization for angles of incidence between  $0^\circ$  and  $70^\circ$  from nadir.

The experiment with water showed that the subsurface depolarization mechanism was dependent on both the number density of particles suspended in the medium and the concentration of dye dissolved in the medium. Also, it indicated that multiple scattering within the turbid water is the primary contribution to the depolarized backscatter for spherical particles.

The data obtained using cast dielectric targets varied from a polarization ratio of approximately unity, to a minimum below the sensitivity of the system. A surface-dependent depolarized return was measured for very rough, non-volume scatter (black) samples which was not present for the smoothest black sample. However, this term was insignificant in contrast to the strong volume scatter samples. The depolarized volume scatter is independent of the surface roughness for incidence angles less than 55°. Also, reciprocity is valid for the depolarization mechanism.

In order to examine the validity of the theoretical development, calculated values from the theory were compared to the experimental data. The results of this indicated that the calculated values and the experimental values had correlation coefficients greater than 90% for most of the data. Therefore, the physical and mathematical approximations utilized in the theoretical analysis appear to be valid.

- [1] J. Leader, "Bidirectional Scattering of Electromagnetic Waves from Rough Surfaces," Presented at the Spring Meeting of the USNC/URSI of the IEEE, Washington, D. C., April 1970.
- [2] J. Rouse, Jr., "The Effect of the Subsurface on the Depolarization of Rough Surface Backscatter, " Radio Science, vol. 7, 1972, pp. 889-895.

Technical Memorandum RSC-68

THE DEPOLARIZATION OF LINEARLY POLARIZED LASER LIGHT  
BACKSCATTERED FROM TURBID WATER

Thomas C. Sheives

*Abstract*

This paper presents the results of an investigation of the depolarization of electromagnetic backscatter from turbid water illuminated by a linearly polarized laser beam. A theoretical volume scatter criteria is presented to explain the depolarization and this model is compared with experimental measurements. Measurements made on aqueous solutions show that the depolarization ratio is very sensitive to different levels of concentration of scattering and absorbing contaminants, and that a volume scatter criteria seems appropriate for explaining depolarized backscatter from turbid water.

Technical Memorandum RSC-72

AN INTRODUCTION TO THE ESTIMATION OF POWER SPECTRA FROM  
SINGLE PARTICLE LDV DATA

W. T. Mayo, Jr., S. Riter, M. T. Shay

*Abstract*

*The single-particle LDV system operating with sparse data provides a need for the ability to estimate the power spectrum of a random process from randomly timed samples whose average rate is less than the "Nyquist rate". In this paper, we review recent literature which indicates that these estimates can be made, provide derivations of several estimators, and describe experiments which verify their validity.*

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Presented at the "Workshop on Laser Doppler Anemometry," Oklahoma State University, Stillwater, Oklahoma, June 11, 1973.

## Technical Memorandum RSC-82

THE DEVELOPMENT OF NEW DIGITAL DATA PROCESSING TECHNIQUES  
FOR TURBULENCE MEASUREMENTS WITH A LASER VELOCIMETER

W. T. Mayo, Jr., M. T. Shay, S. Riter

*Abstract*

A practical method for rapid digital computation of power spectra, from randomly sampled continuous random processes has been developed and tested experimentally. The method will allow computation of power spectra from LDV data obtained at mean data rate less than twice the bandwidth of the velocity fluctuation spectrum. In addition, new expressions for the error in sample mean and turbulence intensity estimates have been derived to include finite-time sample correlation effects.

The theoretical concepts have been tested experimentally. A minicomputer and special purpose digital hardware were used to record sample magnitudes and time differences of a controllable electronic noise process. Data were recorded over a parametric range of mean sample rates.

Good agreement with theory was obtained in predicting the mean square error in the turbulence intensity estimate as a function of the ratio of the mean sample rate to twice the equivalent power bandwidth of the velocity spectrum. The results with the mean estimate showed an increase of estimate error with increasing sample rate, but not as much as predicted. Theoretical prediction of spectrum errors in terms of the system and data parameters has not yet been accomplished. However, empirical error analysis indicates that the optimum mean data rate is less than or equal to twice the spectrum bandwidth when computational efficiency is a major criterion.

*The REMOTE SENSING CENTER was established by authority of the Board of Directors of the Texas A&M University System on February 27, 1968. The CENTER is a consortium of four colleges of the University; Agriculture, Engineering, Geosciences, and Science. This unique organization concentrates on the development and utilization of remote sensing techniques and technology for a broad range of applications to the betterment of mankind.*